UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

EASTERN ENERGY AND LAND USE TEAM
Route 3, Box 44
Kearneysville, West Virginia 25430

Dear Colleague:

The Eastern Energy and Land Use Team (EELUT) is pleased to provide you this report on the effects of acidic precipitation on Atlantic salmon rivers in New England. This report is the eighteenth in our series dealing with air pollution and acid rain. Other reports previously issued are listed on the inside front cover.

This report describes the results of a water chemistry survey conducted in eight rivers in Maine (Narraguagus, Sinclair, Machias, Kerwin, Holmes, Old Stream, Bowles, and Harmon) and one in Vermont (White). All rivers contain actual or potential Atlantic salmon spawning and nursery habitat and the Maine rivers currently have native populations. The White River is undergoing restoration of its population. Results of the survey indicate pH and aluminum concentrations in second and third order streams are within safe limits for Atlantic salmon but first order streams can reach concentrations that may be toxic to sensitive early life stages or during smoltification. These first order streams constitute 20-40% of the available habitat.

Your comments and suggestions on this report are welcomed.

Sincerely,

R. Kent Schreiber

R. Kent Schreiber
Acting Team Leader, EELUT

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October 1984

Air Pollution and Acid Rain
Report 18

EFFECTS OF ACIDIC PRECIPITATION ON ATLANTIC SALMON RIVERS IN NEW ENGLAND

by

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DISCLAIMER

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Executive Summary

A water chemistry survey was conducted in nine Atlantic salmon rivers in New England. Eight rivers are in Maine and contain native Atlantic salmon populations. One river is in Vermont and is undergoing restoration of the Atlantic salmon population. The rivers ranged in size from first order tributary streams to third order main stem rivers. All contained actual or potential Atlantic salmon spawning and nursery habitat.

The chemistry of the Maine rivers was similar to that reported for other rivers located in areas where bedrock is low in acid neutralizing capacity and where precipitation is similarly acidic. The major cation was calcium in all rivers; the major anion was sulfate in all except a few high order streams where bicarbonate concentrations slightly exceeded sulfate. The Vermont river had much higher concentrations of all ions except aluminum and hydrogen than the Maine rivers, especially calcium, magnesium, and bicarbonate, indicating the presence of carbonate mineral in the watershed of this river.

All rivers exhibited a seasonal pattern of chemical change, although changes were relatively small in the Vermont river. River pH, alkalinity, and calcium, magnesium, sodium, and potassium concentrations decreased during periods of high discharge in the spring and fall. Aluminum concentrations increased during high discharge, and sulfate and nitrate concentrations peaked at snowmelt, preceeding peak discharge. High discharge periods resulted from snowmelt and increased precipitation in the spring, and increased precipitation in the fall. The decrease in cations and alkalinity was the result of dilution of base flow by runoff. The decrease in pH (increase in hydrogen ion) probably results from dilution of alkalinity by runoff, and the increase in sulfate and nitrate probably results from the higher concentrations of these ions in snow and runoff than in base flow. Increased aluminum concentrations may result from increased solubility of aluminum in soil and sediment at reduced pH.

The net discharge of total ions from the watersheds exceeds the input of ions from precipitation. The discharge of aluminum and part of the base cations can be accounted for by input of hydrogen ion that is neutralized by ion exchange and weathering reactions in the watershed. The discharge of bicarbonate and the remainder of the base cations cannot be thus accounted for and must therefore reflect internal hydrogen ion generation in the watersheds, probably by dissociation of carbonic acid.

The pH and aluminum concentrations in second and third order streams were well within safe limits for Atlantic salmon, even during periods of high discharge. First order streams, however, reached levels of pH and aluminum concentration that may be toxic to sensitive early life stages of Atlantic salmon, or during smoltification, although conditions were not as severe as those reported for Atlantic salmon streams in southern Norway or southwestern Nova Scotia, where Atlantic salmon populations have declined or disappeared apparently as a result of acidification.

Comparisons of chemical data from two rivers in this study with data for 1969 indicated that conditions were very similar. Slight differences in a few ions could be accounted for by differences in discharge. However,

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aluminum concentrations were much higher in the present study. More acidic deposition could have leached more aluminum from the watershed into the streams, or the difference may result from differences in methodology.

The present chemical conditions in high order streams are not critical for Atlantic salmon survival. However, first order streams, which constitute 20-40% of the available habitat, now approach such conditions, and continued or increased deposition of acid may further degrade conditions in these streams.

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List of Abbreviations and Symbols

Abbreviations

AAS	Atomic absorption spectrophotometry
ANC	Acid neutralizing capacity
CDR	Cation denudation rate
FEP	Fixed end point
IC	Ion chromatography
IP	Inflection point
mg/l	Milligrams per liter
μeq/l	Microequivalents per liter
μg/l	Micrograms per liter
Σ anions	Sum of anions
Σ cations	Sum of cations

Symbols

Al	Aluminum
Ca	Calcium
Cl	Chlorine
F	Fluorine
H	Hydrogen
HCO_3	Bicarbonate
K	Potassium
Mg	Magnesium
Na	Sodium
NO_3	Nitrate
SO_4	Sulfate

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Introduction

Atlantic salmon constitute an anadromous fishery resource of high value. In the United States, Atlantic salmon formerly inhabited major coastal rivers from Maine to Connecticut (Elson and Hord undated). They entered at least 28 rivers and are estimated to have numbered around 300,000 fish (U.S. Fish and Wildlife Service 1983). A combination of low-head dams without fish passage facilities, municipal and industrial pollution of spawning rivers, and overharvest resulted in the extirpation of the species from most of its range by the late 1800s.

Presently, self-sustaining Atlantic salmon populations exist in the Dennys, East Machias, Machias, Narraguagus, Pleasant, and Sheepscot rivers in Maine, and number around 2,000 fish (U.S. Fish and Wildlife Service 1983). Small, self-sustaining populations also exist in a number of small coastal drainage systems (e.g., Ducktrap, Passagassawaukeag, Tunk, and Hobart Stream drainages), and intermittent spawning occurs in additional streams (Beland 1983). Hatchery assisted populations are being developed in the Penobscot, St. Croix, and Union Rivers in Maine, the Merrimack River in New Hampshire, the Connecticut River in Connecticut, Massachusetts, Vermont, and New Hampshire, and the Pawcatuck River in Rhode Island. The hatchery assisted populations number around 4,000 fish (U.S. Fish and Wildlife Service 1983).

The present and historical range of the Atlantic salmon in the United States receives precipitation that is highly acidic, with a mean annual volume weighted pH of 4.2-4.4 (National Atmospheric Deposition Program 1983.) This area is also characterized by low alkalinity surface waters that are vulnerable to acidification (Omernik and Powers 1982). Acidic precipitation has caused acidification of Atlantic salmon spawning rivers and resulted in reduction or elimination of fish populations in southern Norway (Overrein et al. 1980), and southwestern Nova Scotia (Watt et al. 1983). A survey of chemistry of headwater lakes and streams in New England identified a number of Atlantic salmon spawning and nursery streams that were very low in alkalinity (Haines and Akielaszek 1983). Inasmuch as these streams were sampled at summer base flow the pH minima could not be determined.

This study was conducted to determine whether some of the Atlantic salmon resources in New England are at risk from acidification as a consequence of acidic precipitation. We selected nine Atlantic salmon streams for an intensive water chemistry survey. Eight of these were in Maine and presently support major naturally reproducing populations of Atlantic salmon; one was in Vermont and is receiving hatchery introductions. An effort was made to locate previous water chemistry data that could be compared to the present data.

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Methods

Selection of Sampling Sites

The eight streams in Maine (Figure 1) were selected to be representative of first, second, and third order Atlantic salmon spawning and nursery streams in the state. Additional criteria for selection included relatively low color (dissolved organic carbon), low ionic strength, lack of direct human disturbance (roads, logging, etc.), availability of previous chemistry data, and winter access. The White River, Vermont, was also selected for study. The primary criterion was availablity of personnel at the White River National Fish Hatchery to collect, analyze, and ship samples. A secondary consideration was the importance of this river in the restoration plans for the Connecticut River system. The sampling station was located at the White River National Fish Hatchery, Bethel, Vermont. Physical characteristics of the sampling sites are given in Table 1.

Sample Collection Procedure

Open Water Samples

Open water samples were collected by dipping water directly into sample containers at approximately mid-channel. Sample containers were linear polyethylene bottles with polyseal caps. The bottles were acid-washed, distilled water rinsed, and stored filled with deionized, distilled water (specific conductance <2 µS/cm). The bottles were rinsed with sample water three times before being filled. Each set of samples consisted of three bottles -- one 500 ml for pH, alkalinity, specific conductance, and color; one 250 ml for anions; and one 125 ml for cations. The cation sample was preserved with 6.25 ml of 4 N ultrapure nitric acid; the remaining samples were placed on ice until analyzed. During winter months if the stream was completely ice covered a hole was cut through the ice with a 20 cm diameter auger. Ice chips were removed and the sample was then dipped from the hole.

Samples were collected from most streams from about November 1, 1981, to June 1, 1982. The White River was sampled once weekly. The Maine rivers were sampled at various intervals ranging from twice weekly to once every three weeks. Generally, samples were collected more frequently during spring and fall, when chemical conditions were changing rapidly.

Intragravel Samples

Intragravel water samples were collected from two sites, Bowles Brook and Old Stream, in the vicinity of naturally spawned redds. A standpipe was constructed generally similar to the Mark VI groundwater standpipe described by Terhune (1958), except that the pipe used was plastic, annular grooves were omitted, and an oak driving point was cemented into the bottom end. The standpipe was driven into the gravel so that the inlet holes were 25 cm below the gravel surface. A water sampling apparatus was constructed as described in Koo (1964), and was used to pump water from the standpipe into the sample bottles. Samples were then handled as described for open water samples.

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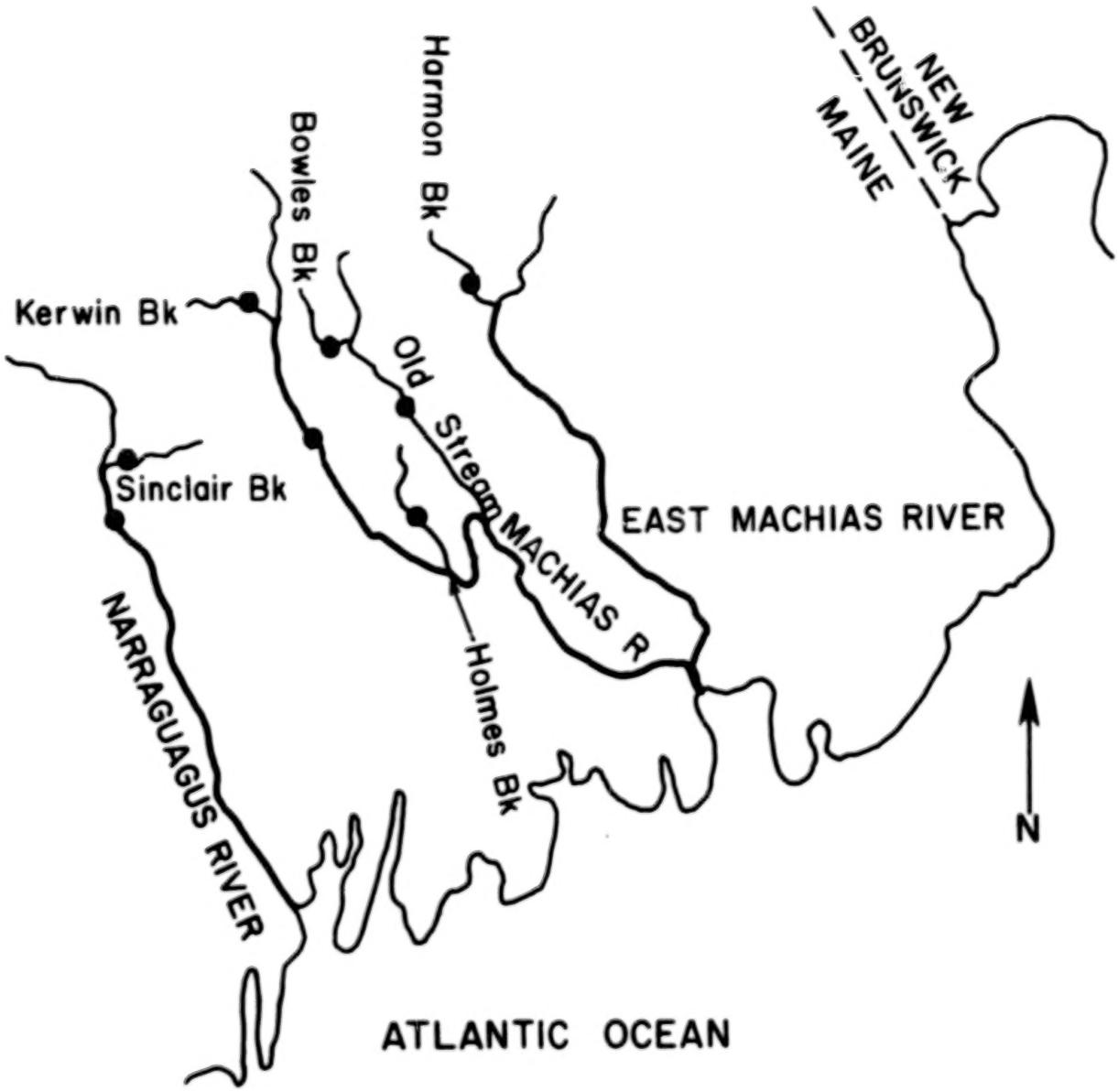

Figure 1. Map showing locations of Maine rivers.

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Table 1. Physical characteristics of the streams selected for study.

River	Drainage Basin	Order	Drainage[a] Area (km^2)	Bedrock[b] Class (percent)	Soil[c] Class (percent)	Mean Color (Pt/Co units)
Narraguagus	Narraguagus	3	581	1 (80%) 2 (10%) 3 (10%)	SS1 (70%) SS2 (30%)	65
Sinclair	Narraguagus	2	11	3 (100%)	SS1 (60%) SS2 (40%)	42
Machias	Machias	3	1,173	1 (30%) 2 (40%) 3 (30%)	SS1 (25%) SS2 (75%)	75
Kerwin	Machias	1	11	1 (100%)	SS1 (40%) SS2 (60%)	94
Holmes	Machias	1	31	1 (75%) 2 (15%) 3 (10%)	SS1 (60%) SS2 (40%)	92
Old Stream	Machias	3	274	1 (50%) 3 (50%)	SS1 (30%) SS2 (70%)	81
Bowles	Machias	2	14	1 (100%)	SS1 (50%) SS2 (50%)	90
Harmon	E. Machias	1	10	2 (10%) 3 (90%)	SS2 (100%)	54
White	Connecticut	3	1,823	2 (60%) 3 (40%)	NS (100%)	0

[a]Drainage area at the mouth of the river, except for the Narraguagus River at Cherryfield, Maine, and the Machias River at Whitneyville, Maine.

[b]1 = low to no buffering capacity (granite, gneiss, quartz, sandstone), 2 = medium/low buffering capacity (sandstones, shale, metamorphic felsic to intermediate volcanic rocks), 3 = medium/high buffering capacity (slightly calcareous, low grade intermediate to mafic volcanic rocks). After Hendrey et al. (1980).

[c]NS = mostly non-sensitive soils, soils are calcareous or subject to frequent flooding, cation exchange capacity (CEC) >15.4 meq/100g; SS1 = slightly sensitive soils dominate, CEC = 6.2 to 15.4 meq/100g; SS2 = slightly sensitive soils significant but cover less than 50% of the area. After McFee (1980).

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Analytical Methods

Field Procedures

Analyses of pH, alkalinity, specific conductance, and color were performed at field locations. Within 8 hours after sampling, and as soon as possible, the 500 ml bottle was removed from ice and warmed to room temperature. Two 100 ml aliquots were removed for determination of pH and alkalinity. The pH was measured with a portable meter (Fisher model 107 or Cole Parmer DigiSense) equipped with a plastic-body, gel filled, combination electrode. The meter was standardized with pH 7.00 and 4.01 NBS certified buffers, and electrode response was verified by measuring the pH of dilute sulfuric acid solutions of theoretical pH 4.00. If measured values deviated from expected values by more than 0.1 pH units the electrode was discarded. The electrode was rinsed thoroughly with distilled water, blotted dry, and soaked in the sample for 15 minutes or longer -- until three successive readings at 1 minute intervals were identical -- and pH was recorded.

Alkalinity was determined by titrating each of the 100 ml sample aliquots with 0.0200 N sulfuric acid to pH <4. Acid was added in 0.10 ml portions using a micro syringe until pH 5 was reached, then in 0.05 ml portions to pH <4. The pH was recorded after equilibration following each addition of acid. Alkalinity was calculated by two methods. Inflection point alkalinity was determined by the method of Gran (Stumm and Morgan 1981), and fixed endpoint (pH 4.5) alkalinity was determined as described in American Public Health Association et al. (1975). Inflection point results were used for all analyses and comparisons except for those using previous data, where fixed endpoint data were used.

Two 50 ml aliquots of sample were measured and used for determination of specific conductance and color. Specific conductance was measured with a calibrated meter (Markson Scientific Company model 10), and apparent color was determined by comparison of unfiltered samples with platinum cobalt standard solution (LaMotte Chemical Company, Chestertown, Maryland). Stream discharge data for the Narraguagus and White rivers were obtained from the U.S. Geological Survey. Precipitation chemistry data for the Acadia National Park, Maine, and Hubbard Brook, New Hampshire, sites were obtained from the National Atmospheric Deposition Program. Data for amount of precipitation in the study areas were obtained from various U.S. Weather Bureau sites.

Laboratory Procedures

The remaining water samples were kept on ice, returned to the laboratory, and kept refrigerated until analyzed. The acidified sample was analyzed for cations. Sodium and potassium were determined by air-acetylene flame atomic absorption spectrophotometry (AAS; Perkin Elmer model 703), calcium and magnesium were determined by nitrous oxide-acetylene flame AAS, and aluminum by graphite furnace AAS. Samples were not filtered. The unacidified samples were filtered through Whatman 42 ashless filters and analyzed for chloride, nitrate, sulfate, and fluoride by ion chromatography (Dionex model 16) following the manufacturer's recommended procedures. Organic anions were estimated by

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first estimating dissolved organic carbon (DOC) from color measurements using a linear regression equation derived previously (Haines and Akielaszek 1983), then multiplying DOC by the factor 0.6 to obtain μeq/l of organic anions (A. Henriksen, Norwegian Institute of Water Research, personal communication). Where necessary, ions were corrected for marine aerosol input by assuming that all chloride resulted from marine aerosols and that the ratio of other ions to chloride was the same in marine aerosols as in sea water. Non-marine ion concentrations were obtained by subtracting estimated marine contributions from total ion concentrations. Because all sampling sites were upstream from roads, and all except the White River were remote from any road, the influence of deicing salt on chloride concentrations was expected to be minimal.

Quality assurance of analytical procedures was performed as specified in a quality assurance project plan filed with the U.S. Environmental Protection Agency. Analytical instruments were maintained and serviced regularly, and precision was determined by analysis of U.S. Environmental Protection Agency Water Pollution Quality Control Samples for Trace Metals, and Minerals (EPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio). Ionic balance and calculated (theoretical) versus measured specific conductance also were used as a check on analytical accuracy and data coding errors. Theoretical specific conductance was calculated by multiplying ion concentrations by equivalent conductance values (Weast 1978).

Most previous water chemistry data located for the rivers studied consisted largely of single grab samples, or samples collected at infrequent intervals. The most useful data were very complete chemical analysis of monthly water samples from the Narraguagus and Machias Rivers, collected in 1969. These data were located in an unpublished report (intended as a Master of Science thesis but never defended) in the files of the Maine Cooperative Fishery Research Unit, University of Maine.

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Results

Quality Assurance

The laboratory analyses of EPA Water Pollution Quality Control Samples for Minerals (Table 2), and Trace Metals (Table 3) gave acceptable precision. The precision we obtained equalled or exceeded that of the laboratories reported by EPA in all cases. The bias for mineral analyses was less than 10%, but bias for aluminum and manganese frequently exceeded 10%. Bias was generally lowest for the highest concentrations. No correction for bias was applied to the results presented later.

A further check on data quality was made by comparing measured and calculated specific conductance (Figure 2). The intercept of the regression is slightly less than zero and the slope is somewhat greater than one. This indicates that the calculated values exceed measured values at high concentrations. Additionally, cations and anions were summed separately for each sample, and total cations were plotted against total anions (Figure 3), which gave very similar results.

Precipitation and Discharge

The mean monthly precipitation received, and mean monthly depth of snow on the ground at the nearest weather bureau station for the Maine rivers and the White River are shown in Table 4. Precipitation is considerably higher in Maine than in Vermont. Precipitation is higher in spring and fall than in summer and winter in both areas, but the timing of the precipitation maxima shifts from year to year. Both areas generally have snow on the ground from November to April, but snow depth is greater in Vermont.

Two of the rivers, Narraguagus and White, contain hydrologic gauges operated by the U.S. Geological Survey. Daily discharge for each sample date for these rivers (Figure 4) is highly variable but tends to be highest in spring and fall, and lowest in summer and winter. Intense precipitation events can increase discharge at any time of year. The 1981 water year was characterized by multiple discharge peaks.

Chemical Factors

pH, Alkalinity, and Conductance

The pH, alkalinity, and conductance values followed similar temporal patterns in all rivers (Figures 5-13) and were negatively correlated with discharge (except for pH in the White River; Table 5). The general pattern was relatively high values during winter, a sharp decline at spring peak discharge, increasing values during summer, a decline in autumn, and an increase in winter. This pattern was clear for 1980 and 1982 in the Narraguagus, Machias, and Kerwin streams, but was obscured during 1981. In the remaining streams pH, alkalinity, and conductance increased from autumn to winter, were relatively high and stable during winter, declined at spring peak discharge, and increased during summer. Higher order streams had higher pH, alkalinity, and conductance values at all times of the year than did lower order streams.

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Table 2. Results of Analysis of EPA Water Pollution Quality Control Sample for Minerals. Mean Values of pH were Computed from Hydrogen Ion Concentrations.

EPA Sample Number	Factor	True Value	Laboratory Results			
			X (N=3)	S.D.	Precision	Bias
3	pH (units)	7.4	7.54	0.01	±0.3%	+1.9%
	Calcium (mg/l)	6.7	6.8	0.2	±5.9%	+1.5%
	Magnesium (mg/l)	2.4	2.4	0.05	±4.2%	0
	Potassium (mg/l)	1.7	1.6	0.06	±7.5%	-5.9%
	Sodium (mg/l)	7.0	7.2	0.06	±1.7%	+2.8%
	Sulfate (mg/l)	12.0	12.0	0.08	±1.3%	0
	Chloride (mg/l)	20.5	20.3	0	±0	-1.0%
4	pH (units)	8.6	8.56	0.02	±0.5%	-0.5%
	Calcium (mg/l)	32.0	34.8	0.2	±1.2%	+8.8%
	Magnesium (mg/l)	7.1	7.1	0.1	±2.8%	0
	Potassium (mg/l)	7.2	7.5	0.06	±1.6%	+4.2%
	Sodium (mg/l)	40.0	40.1	0.1	±0.5%	+0.3%

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Table 3. Results of Analysis of EPA Water Quality Control Samples for Trace Metals. All units are µg/l.

EPA Sample Number	Trace Metal	True Value	Laboratory Results				EPA Recovery			
			X (N=3)	S.D.	Precision	Bias	X	S.D.	Precision	Bias
1	Al	350	424.3	29.9	±14.1%	+21.2%	369	41.7	±22.6%	+ 5.4%
	Mn	55	62.3	2.6	± 8.3%	+13.3%	54.8	5.7	±20.8%	- 0.4%
2	Al	50	68.3	5.5	±16.1%	+36.6%	74.9	24.3	±64.9%	+49.8%
	Mn	11	13.7	0.6	± 8.8%	+24.5%	11.0	3.8	±69.1%	0
3	Al	700	726.7	46.2	±12.7%	+ 3.8%	712	62.1	±17.4%	+ 1.7%
	Mn	350	387.5	6.5	± 3.4%	+10.7%	348	18.6	±10.7%	- 0.6%

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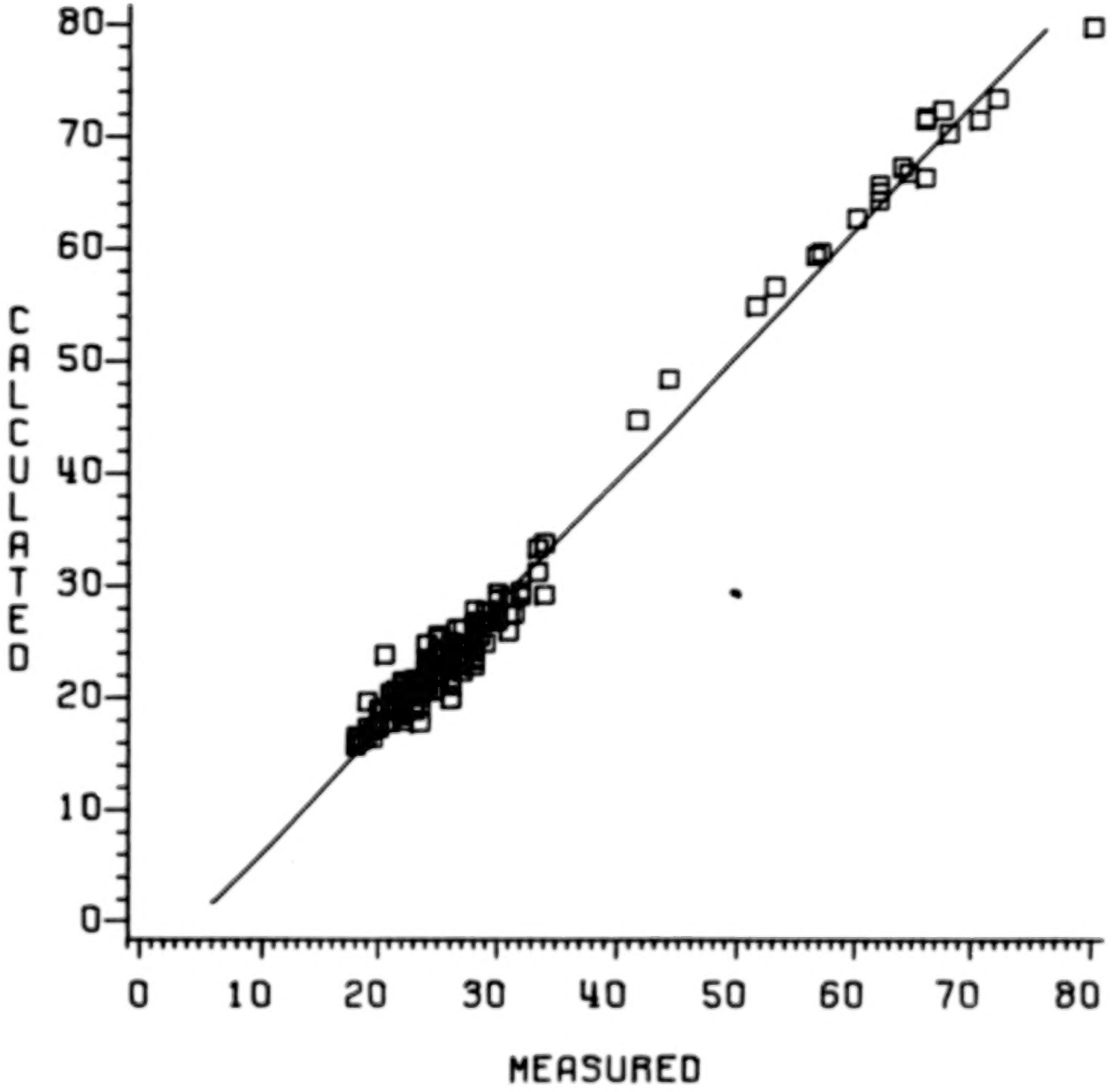

Figure 2. Calculated versus measured specific conductance. Regression equation: Calculated = -5 + 1.11 Measured (r^2 = 0.99, p = 0.0001, N = 173).

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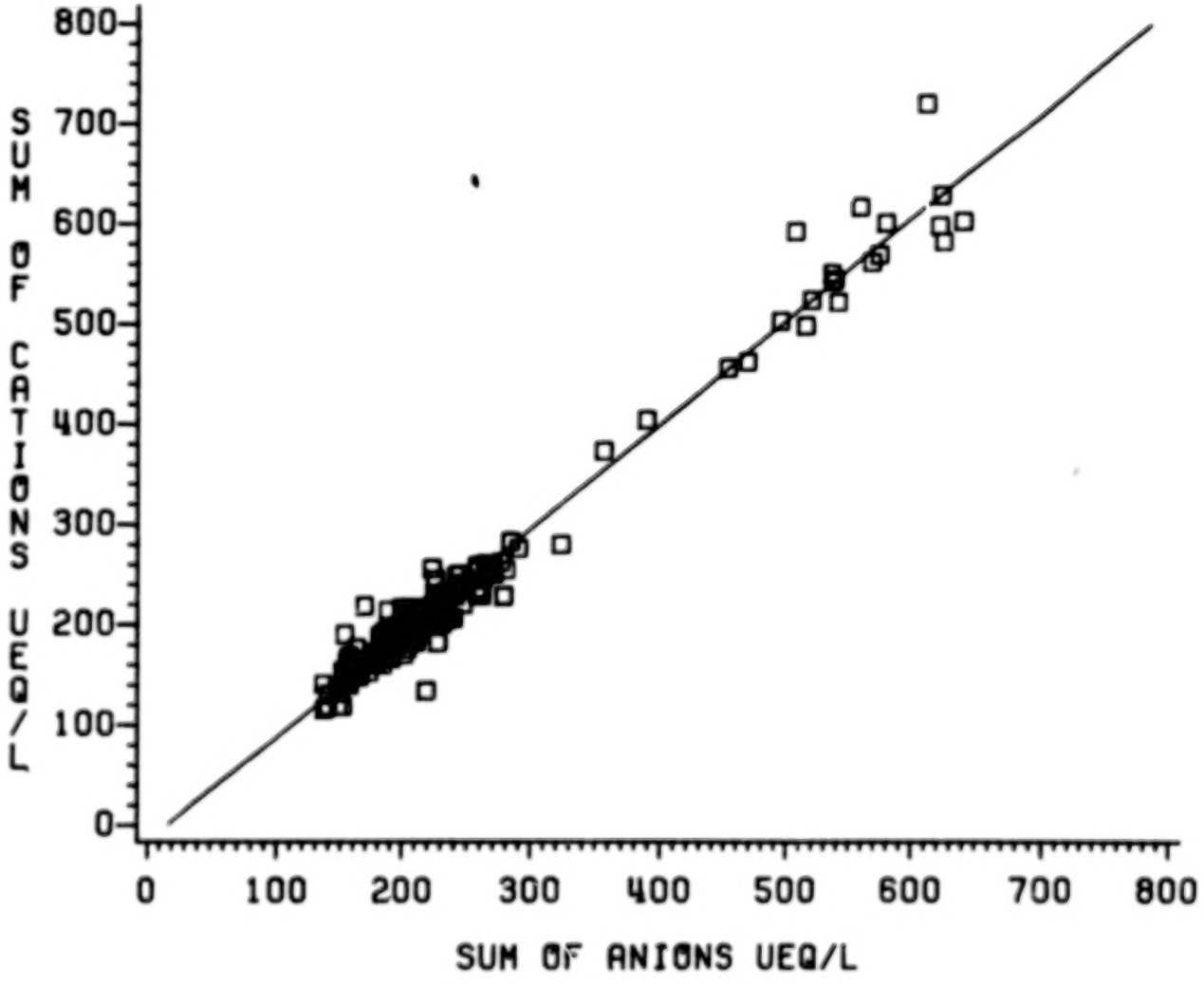

Figure 3. Sum of cations versus sum of anions. Regression equation: cations = -16 + 1.04 anions (r^2 = 0.97, p <0.0001, N = 173).

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Table 4. Mean monthly precipitation, 30 year average precipitation (1931-1960), and mean monthly snow depth, in mm, for Jonesboro, Maine, and Montpelier, Vermont, during the study period.

	Jonesboro							Montpelier				
	Precipitation				Depth of Snow			Precipitation			Depth of Snow	
Month	1980	1981	1982	30 yr Avg	1980	1981	1982	1981	1982	30 yr Avg	1981	1982
Jan	39	47	158	123	22	373	325	5	75	91	127	630
Feb	56	70	91	107	126	52	469	159	46	77	53	663
Mar	157	59	86	107	86	87	293	16	70	98	109	434
Apr	130	174	121	104	2		31	66	47	99		41
May	23	109	20	90				143	42	101		
Jun	91	126	122	95				92	170	102		
Jul	89	183	93	86				91	27	105		
Aug	36	91	108	79				83	58	89		
Sep	110	126	67	113				146	52	100		
Oct	159	121	49	104				79	41	86		
Nov	175	113	115	134	34	2		39	77	104	8	3
Dec	84	217	58	114	180	55	47	59	38	89	437	16
Total	1,149	1,436	1,087	1,255				979	719	1,142		

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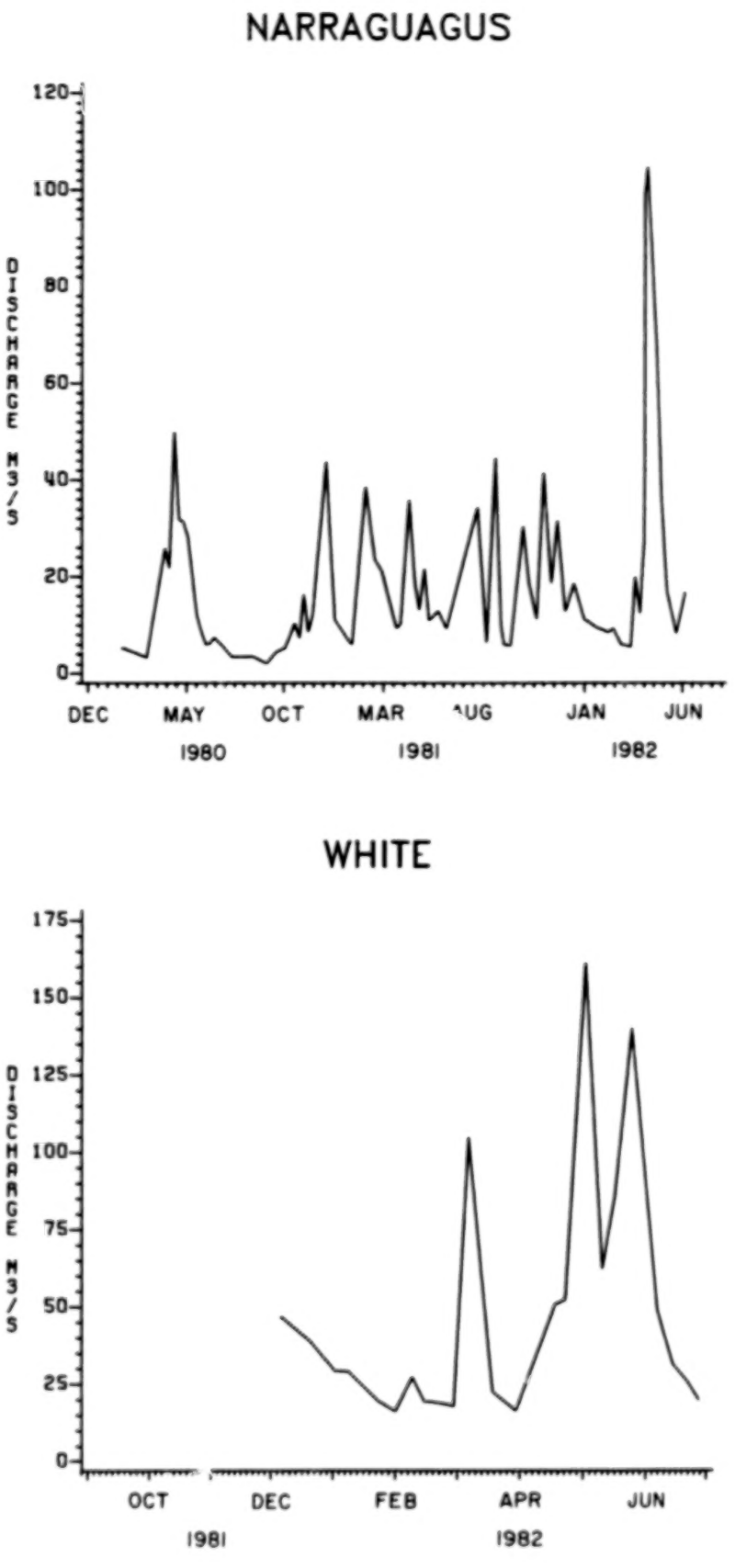

Figure 4. Discharge of the White and Narraguagus rivers.

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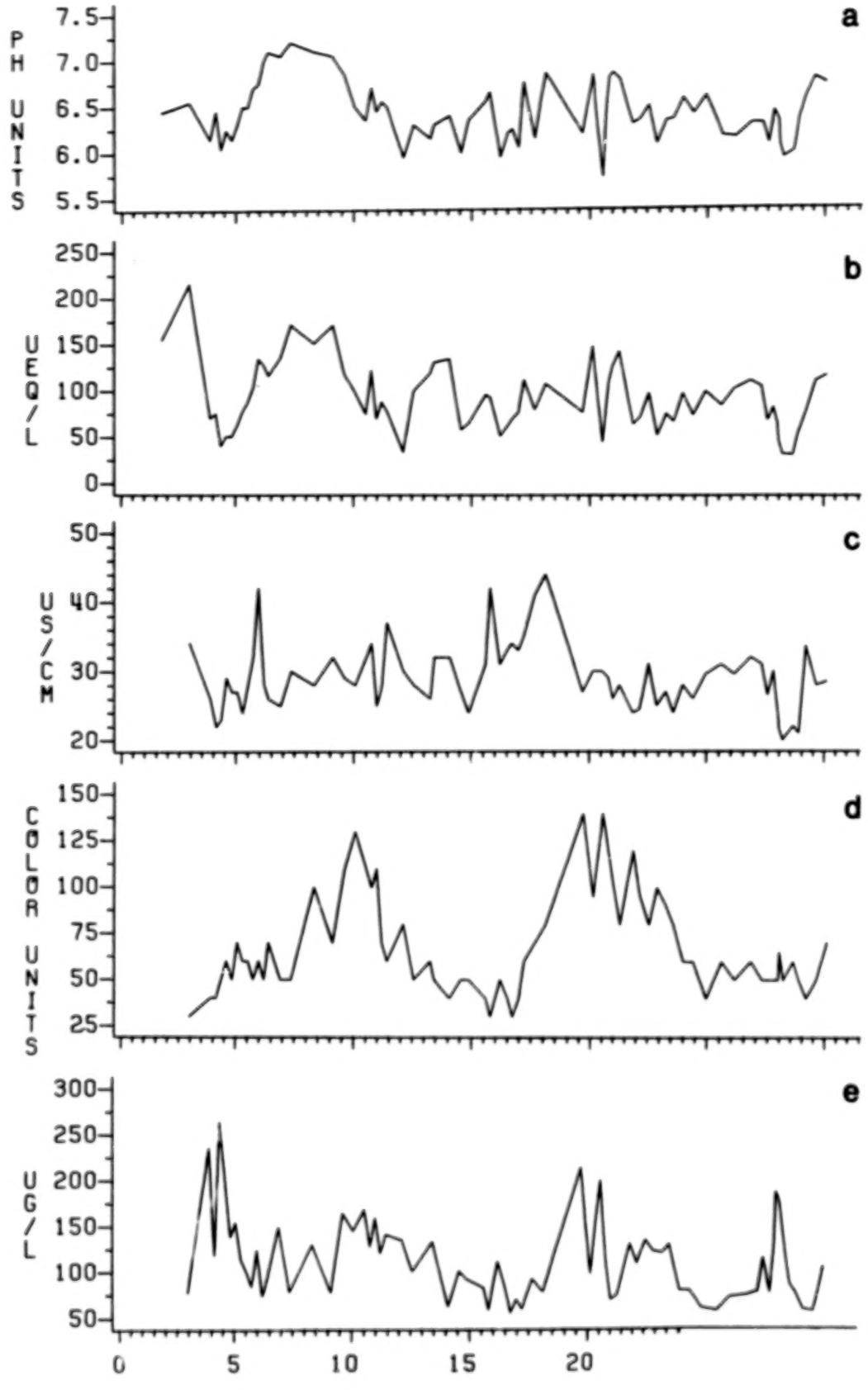

Figure 5. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for the Narraguagus River.

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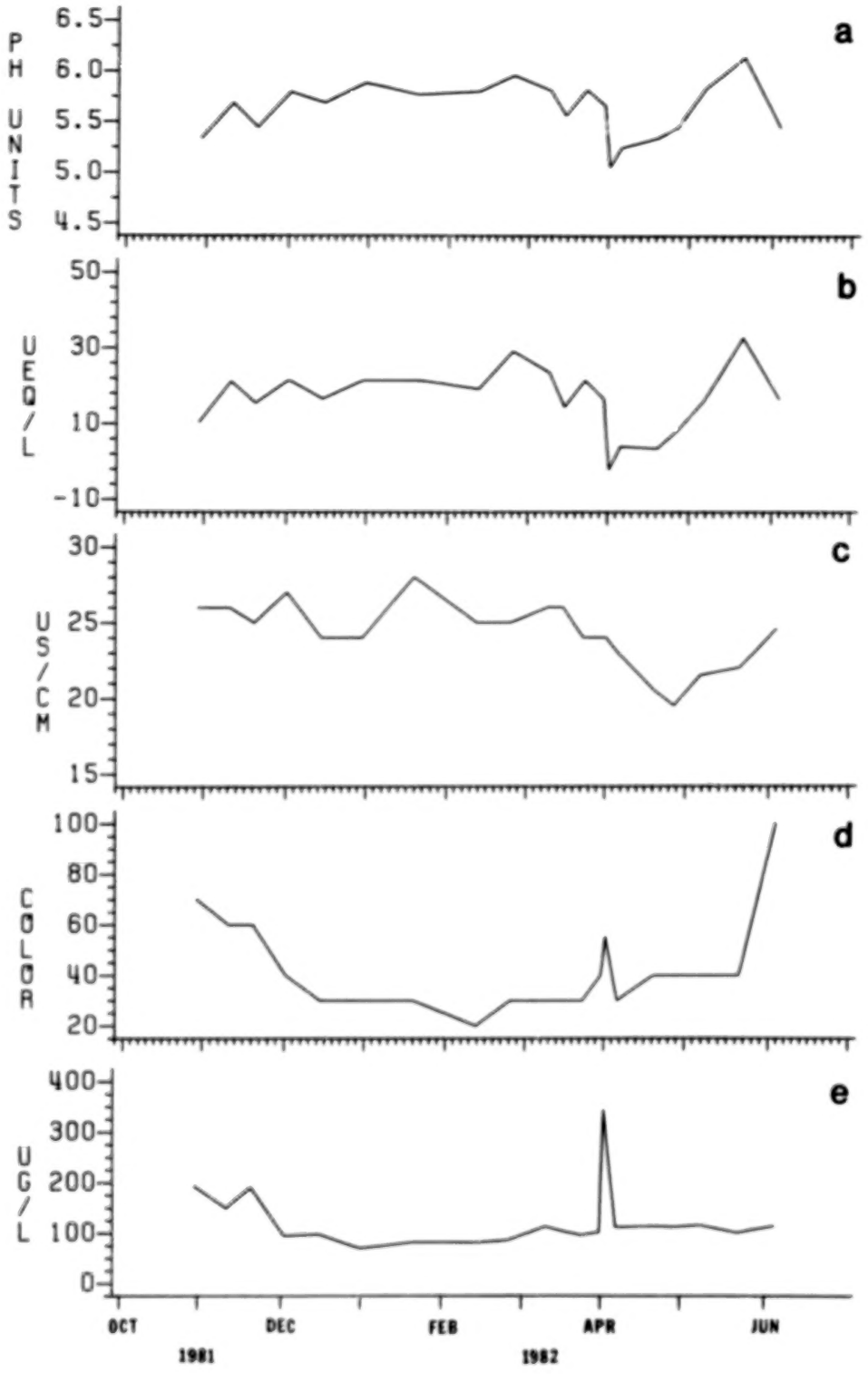

Figure 6. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Sinclair Brook.

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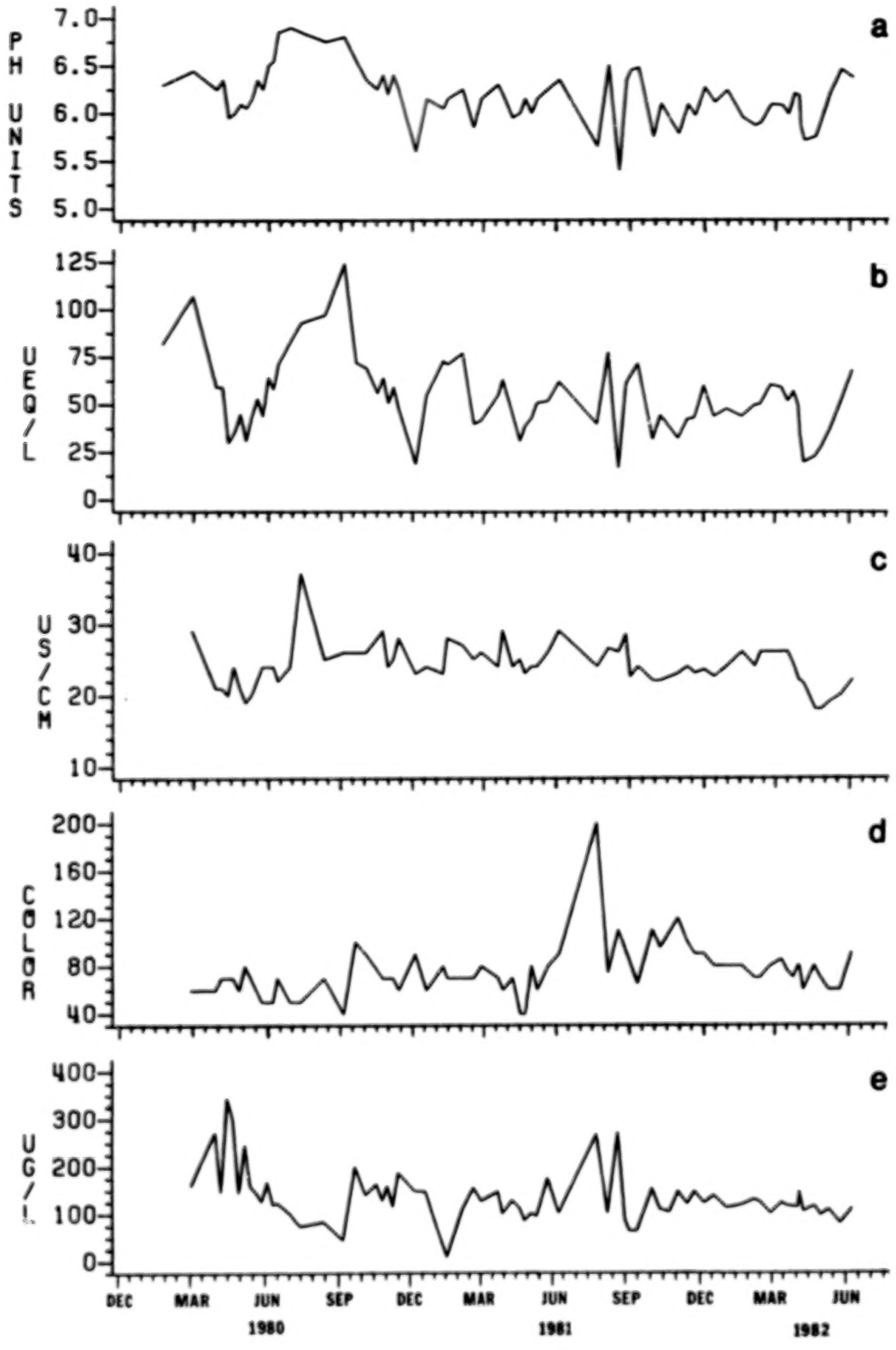

Figure 7. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for the Machias River.

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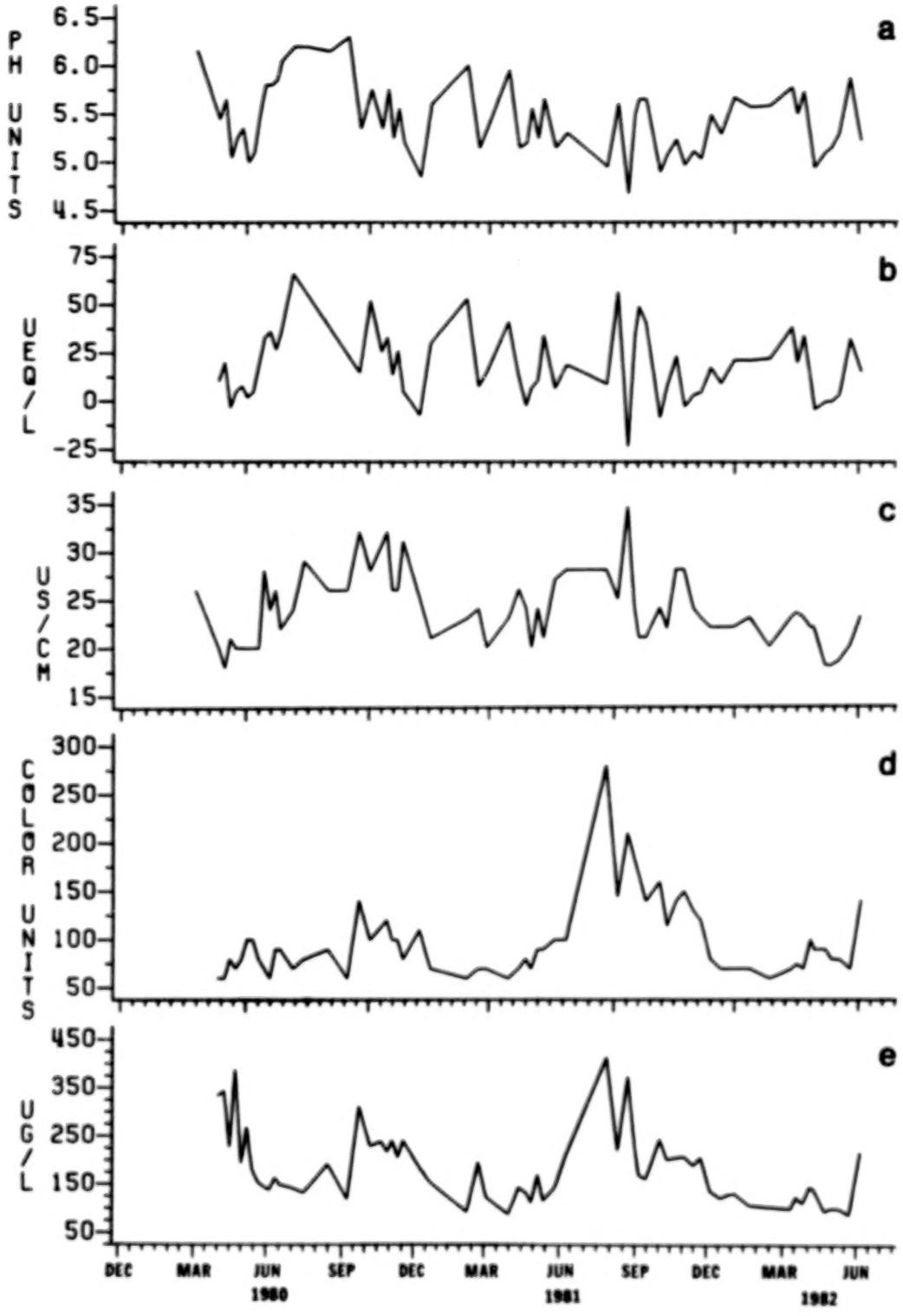

Figure 8. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Kerwin Brook

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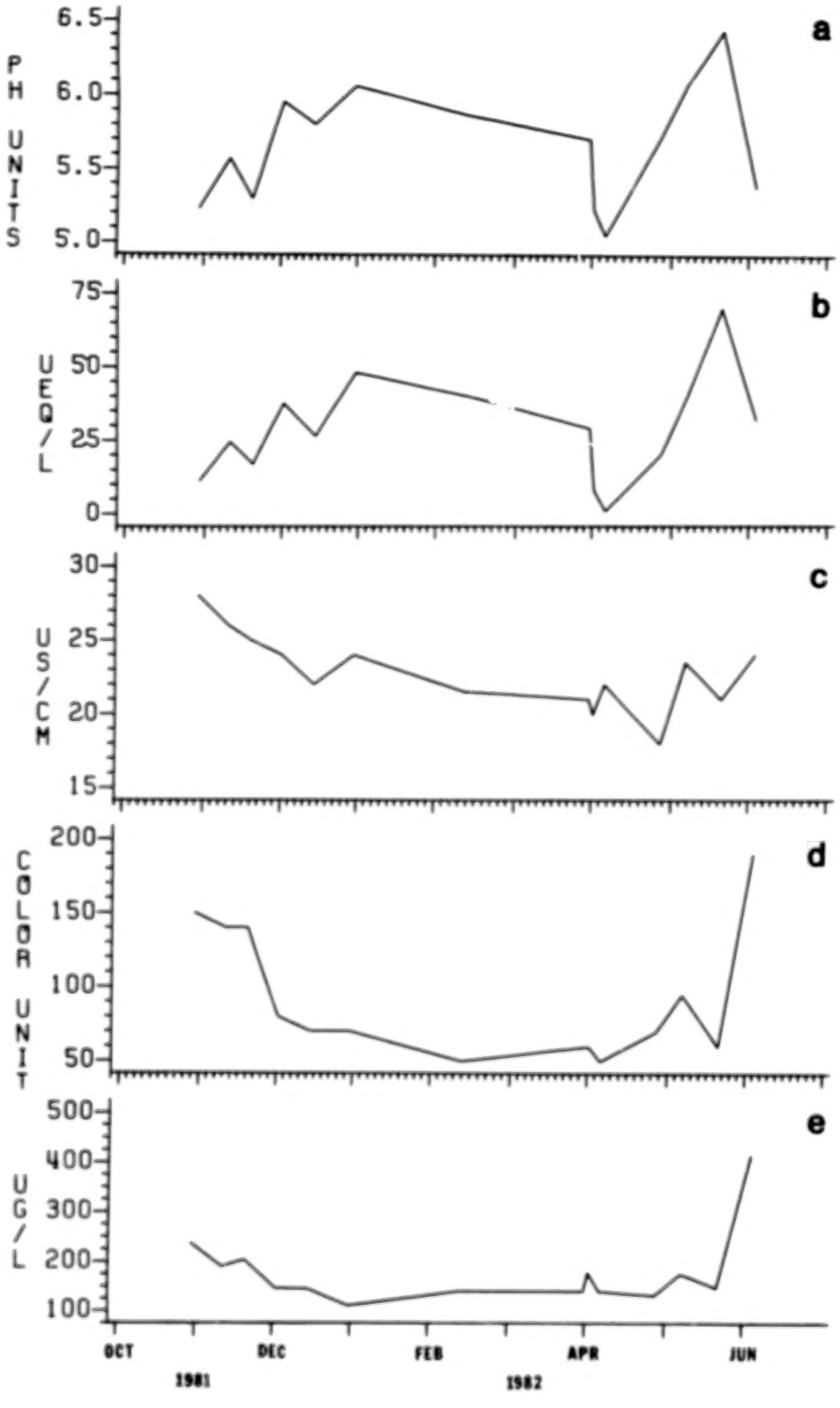

Figure 9. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Holmes Brook.

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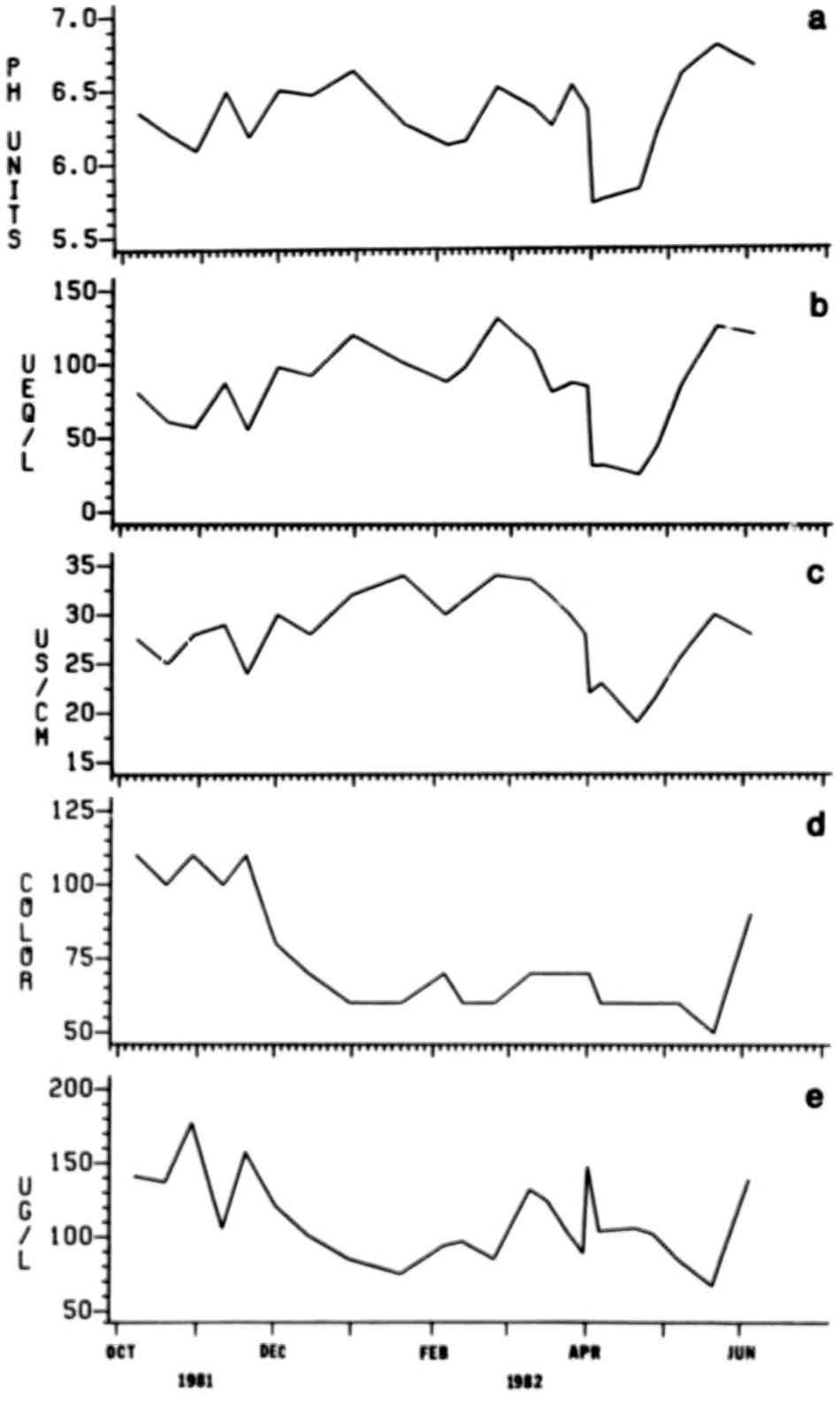

Figure 10. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Old Stream.

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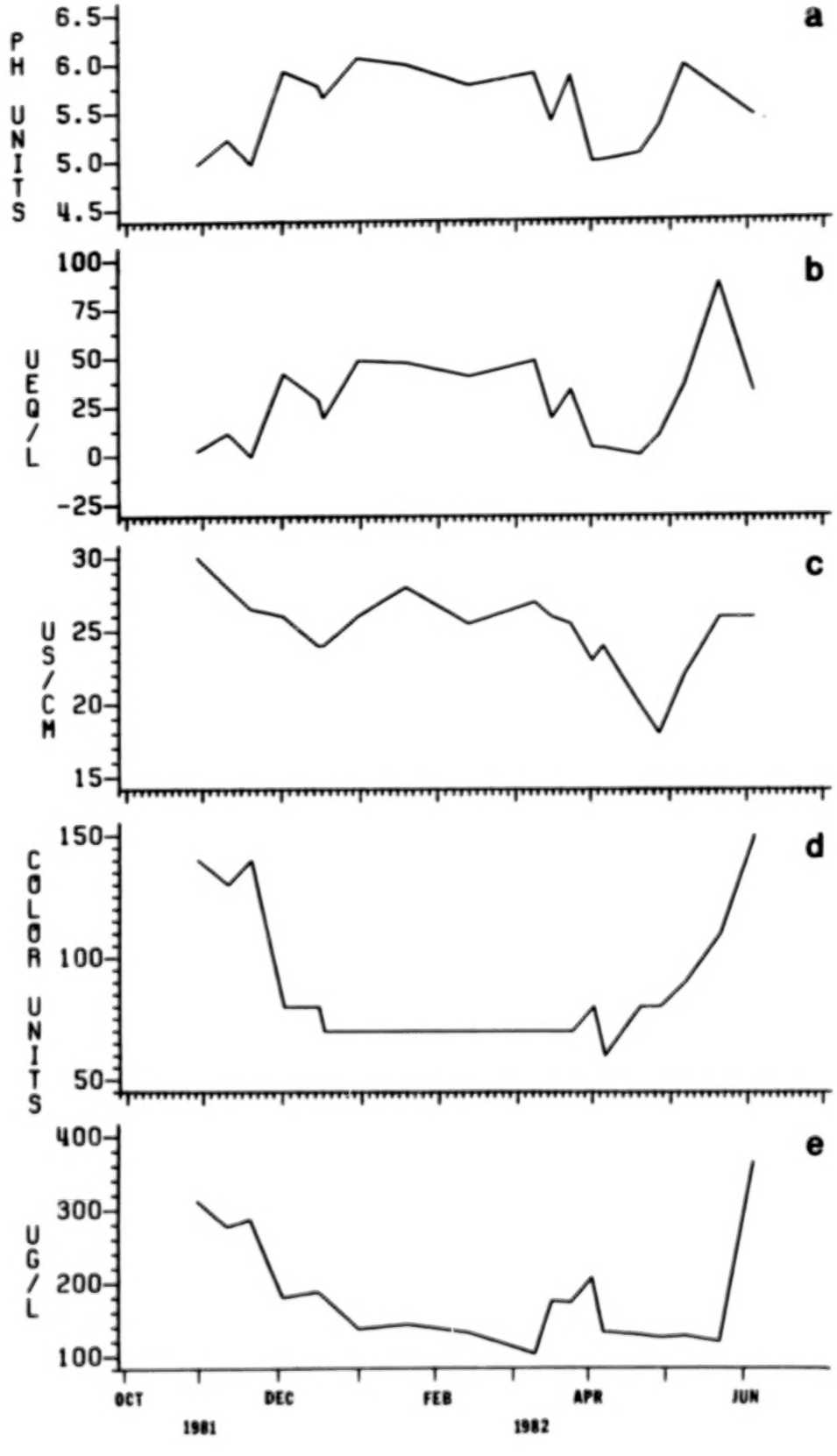

Figure 11. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Bowles Brook.

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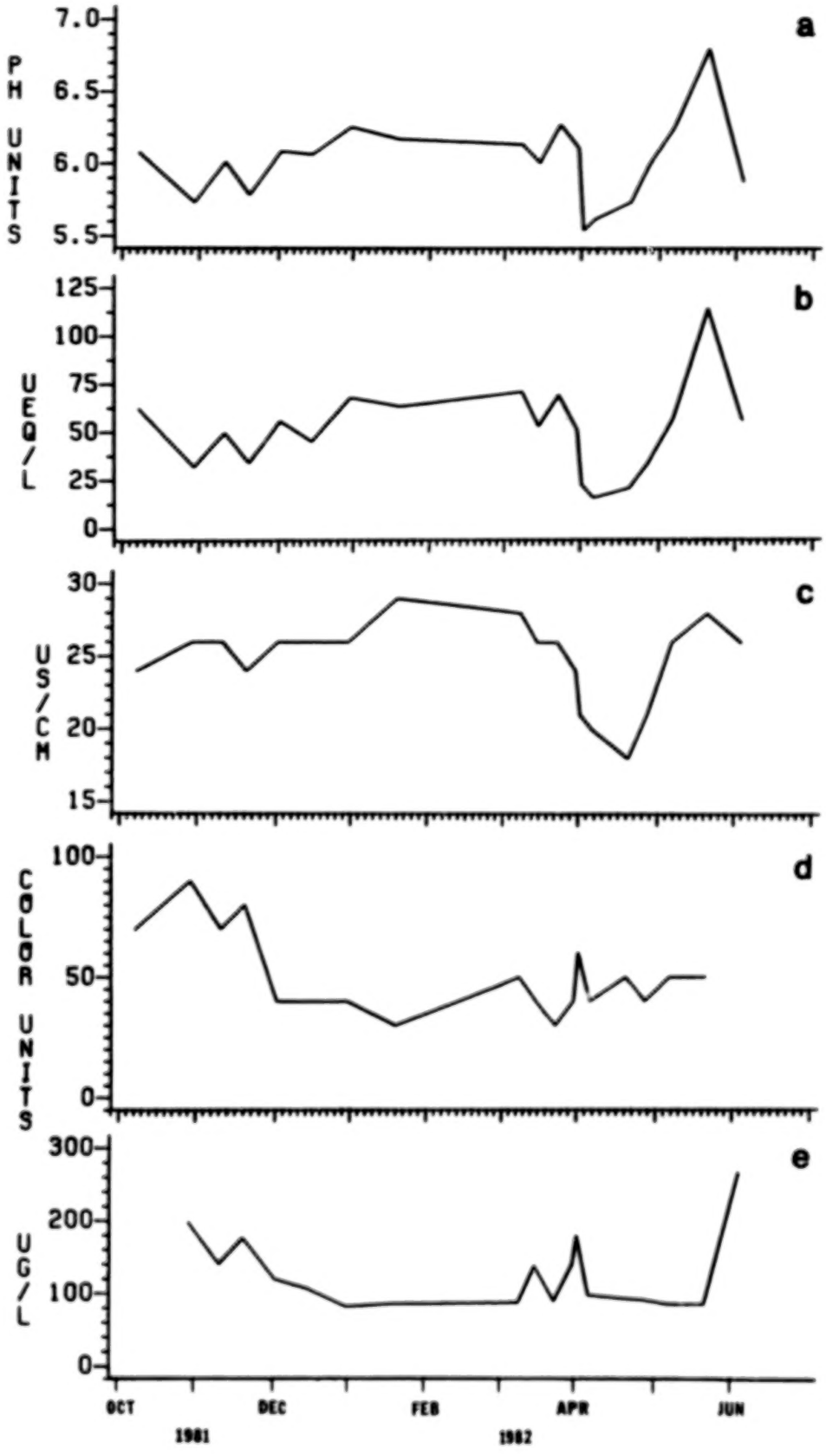

Figure 12. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for Harmon Brook.

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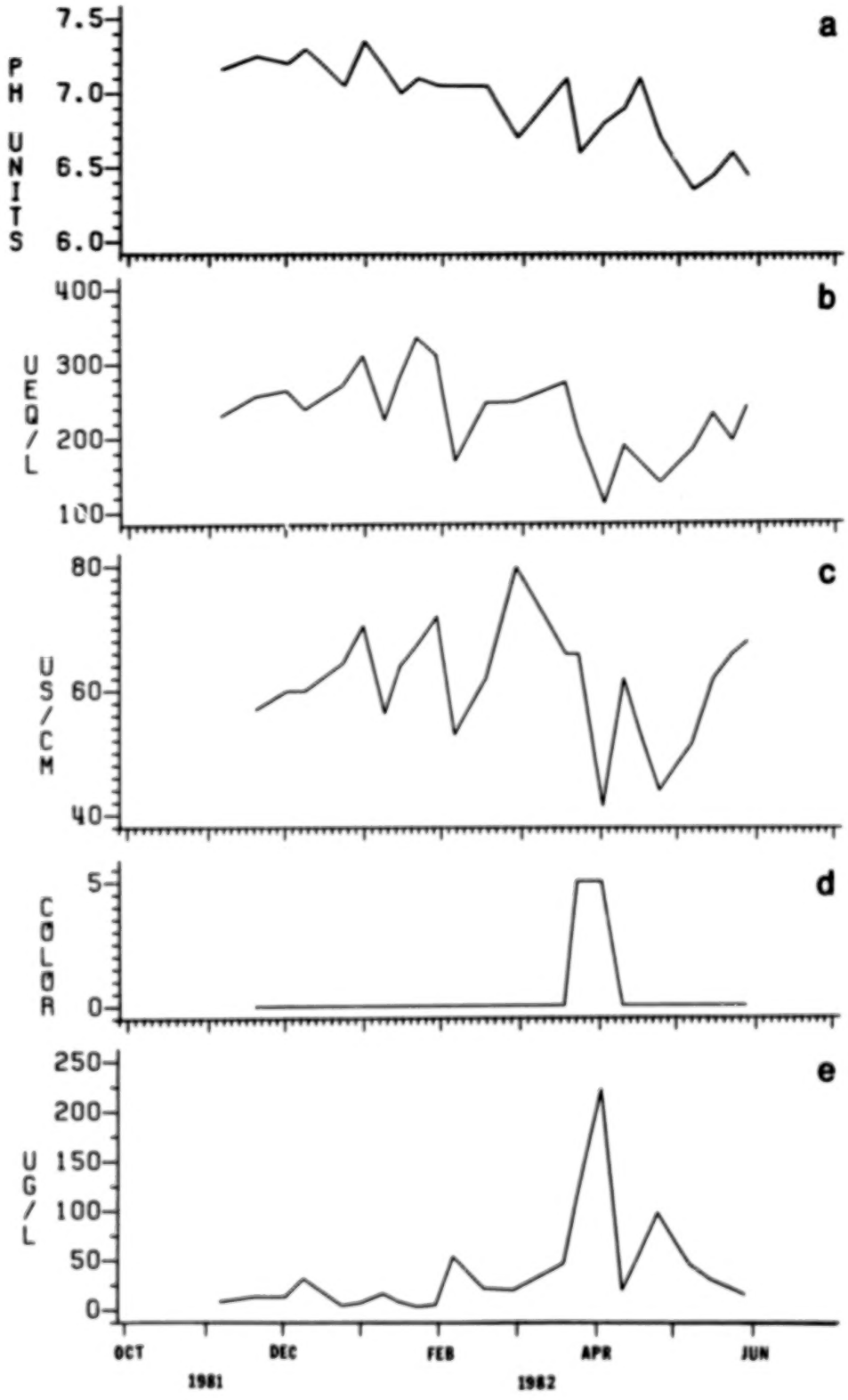

Figure 13. Variation of pH (a), alkalinity (b), specific conductance (c), color (d), and aluminum (e) over time for the White River.

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Table 5. Pearson product moment correlations of physical and chemical factors with discharge for the two gauged streams.

Factor	White R.	Narraguagus R.
pH	-0.15	-0.62
Alkalinity	-0.82**	-0.67
Specific Conductance	-0.82**	-0.48
Color	0.47*	0.04
Calcium	-0.85**	-0.62
Magnesium	-0.55**	-0.51
Sodium	-0.47*	-0.37**
Potassium	-0.51*	0.02
Aluminum	0.83**	0.45
Sum of cations[a]	-0.77**	-0.61
Sulfate	-0.80**	-0.16
Nitrate	0.35	-0.02
Chloride	-0.31	-0.24
Fluoride	-0.17	-0.50
Sum of anions	-0.81**	-0.80

[a] Excluding aluminum.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.

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Color

The White River was virtually colorless; the Maine rivers were moderately colored, ranging from 20 to nearly 300 units and averaging 30-40 units (Figures 5-13). Color changed seasonally, being lowest from late winter to early summer and highest from late summer to early fall. However, color was not correlated with discharge (Table 5). Color appeared to decline in winter, when discharge was low, and did not increase until summer, when discharge was also low.

Aluminum

Aluminum concentration exhibits a seasonal cycle that is the inverse of that for pH and alkalinity (Figures 5-13). Concentrations are highest when pH is lowest and alkalinity is lowest. Aluminum is significantly positively correlated with discharge in the two gauged rivers (Table 5), and with pH in all rivers combined (Figure 14). Aluminum concentrations are generally higher in lower order streams, which are also lower in pH than higher order streams. A linear regression of aluminum with color yielded significant regressions in three of eight rivers. Regression was not performed for the White River as color was zero for all but one sample date. The significant ($p < 0.0001$) regressions were for Bowles Brook ($r^2 = 0.73$), Holmes Brook ($r^2 = 0.73$), and Harmon Brook ($r^2 = 0.77$). Aluminum may have been bound to dissolved to organic compounds in these streams. We measured only total aluminum in this study.

Cations

Mean cation concentrations for the period of measurement are given in Table 6, and temporal trends are shown in Figures 15-23. Cation concentrations were generally higher in the higher order streams. Calcium was the most abundant cation in all third order streams. Sodium exceeded calcium in all first and second order streams except Harmon Brook, where calcium was most abundant. Sodium was nearly as abundant as calcium in all Maine rivers, but was much lower than calcium in the White River. Magnesium was intermediate and potassium was lowest in concentration in all streams.

Potassium concentrations were nearly constant over time with no apparent temporal pattern. Magnesium was relatively constant over most of the year but concentrations generally declined in spring during the period of snow melt and high discharge. This occurred in April in 1980 and 1982, but multiple discharge peaks occurred in 1981 (December 1980, March, May, July, and August 1981). Snow cover disappeared in February and March in 1981.

Calcium and sodium had similar seasonal patterns of concentration. Concentrations were highest in August and lowest in April in 1980 and 1982. Again, 1981 was characterized by multiple cycles. Sodium concentrations in the Narraguagus River were different from calcium in 1980, but were similar thereafter. All cations were negatively correlated with discharge (Table 5), except potassium in the Narraguagus River.

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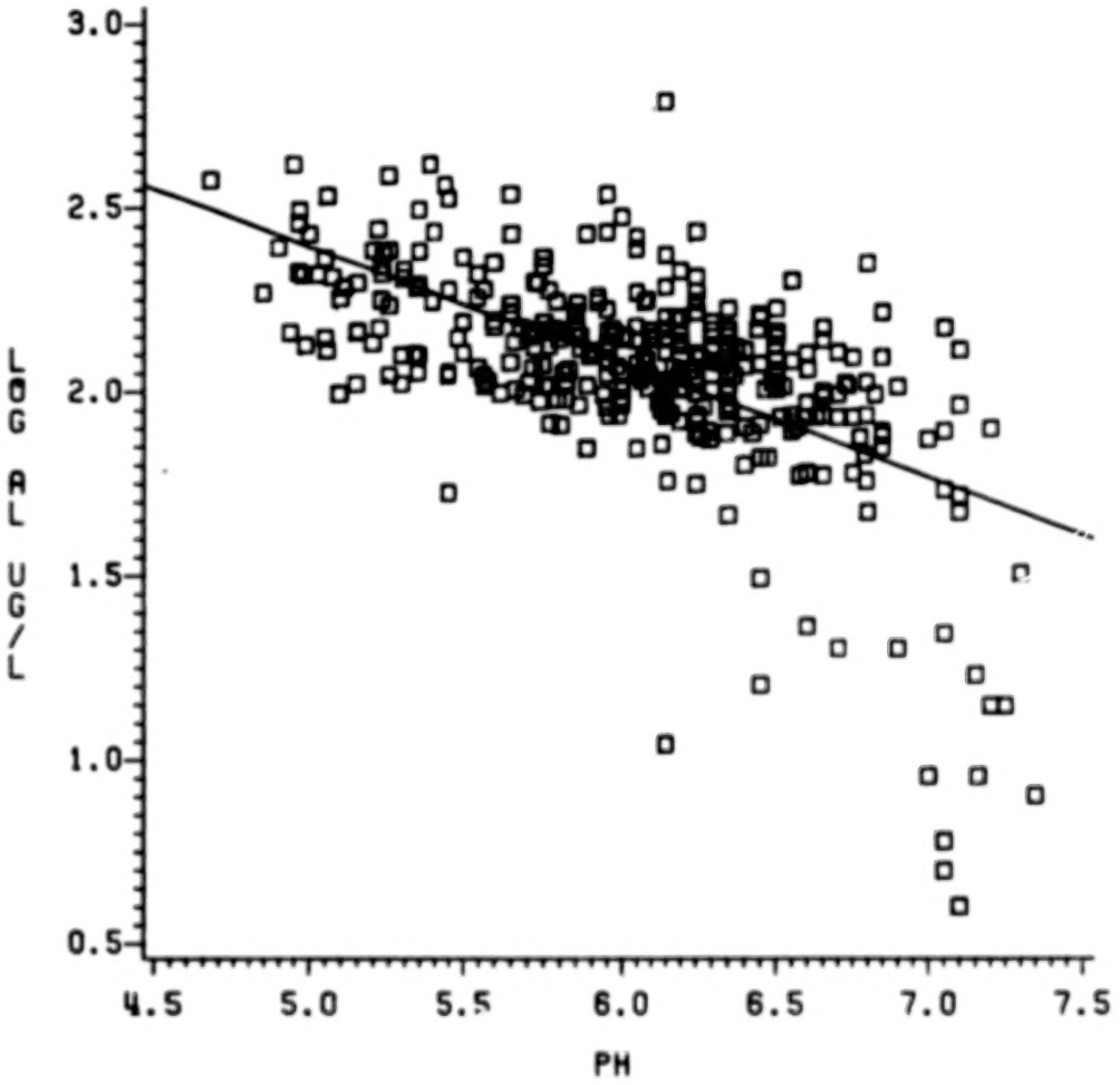

Figure 14. Linear regressions of $\log_{10}$ total aluminum concentration on pH. Regression equation: Log_{10} Al = 3.97 - 0.31 pH (r^2 = 0.36, p <0.0001, N = 333).

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Table 6. Mean chemical concentrations, for the period of measurement in the nine streams, organized by watershed and order. Units are μeq/l except as noted.

Watershed and Site	Order	pH	Color[a]	Cations					Anions					
				Al[b]	Ca	Mg	Na	K	SO_4	NO_3	HCO_3	Cl	F	Organic
Narraguagus														
Sinclair Bk.	1	5.56	65	123	54	39	67	13	65	23	19	53	1	25
Narraguagus R.	3	6.33	42	112	118	38	82	14	56	7	93	51	3	39
Machias														
Kerwin Bk.	1	5.31	75	192	70	29	77	12	55	2	28	43	6	57
Holmes Bk.	1	5.52	94	179	63	41	71	7	49	3	32	55	1	55
Bowles Bk.	2	5.36	92	185	68	39	73	10	59	4	31	53	2	54
Old Str.	3	6.19	81	114	115	41	77	10	56	3	85	59	2	49
Machias R.	3	6.09	90	136	87	32	70	11	50	3	55	42	3	45
E. Machias														
Harmon Bk.	1	5.95	54	126	77	38	72	8	65	3	52	45	2	33
Connecticut														
White R.	3	6.83	<1	39	324	94	112	10	134	41	234	126	1	<1

[a] Color units = mg/l of platinum cobalt standard solution. [b] μg/l.

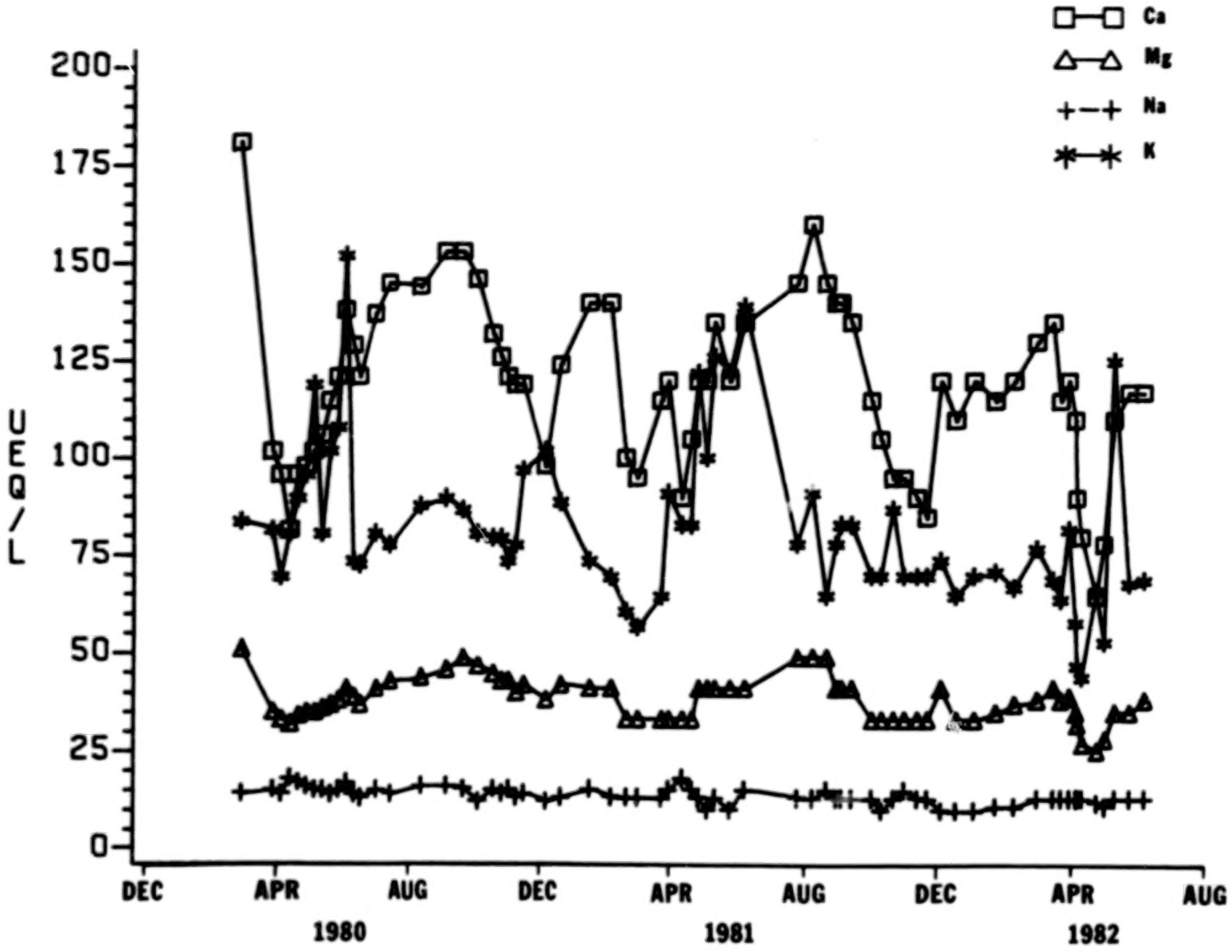

Figure 15. Variation of total concentrations of base cations over time for the Narraguagus River.

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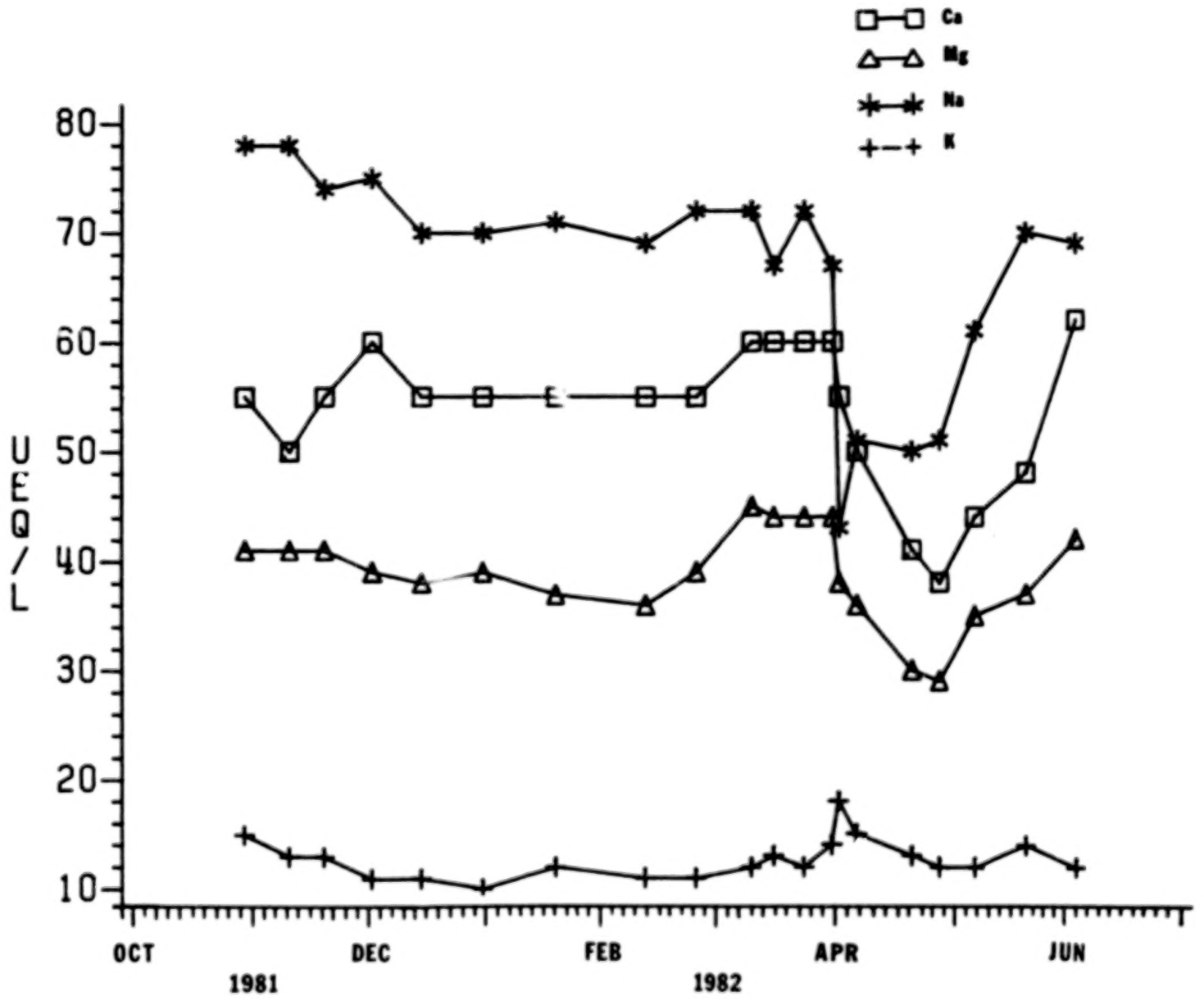

Figure 16. Variations of total concentrations of base cations over time for Sinclair Brook.

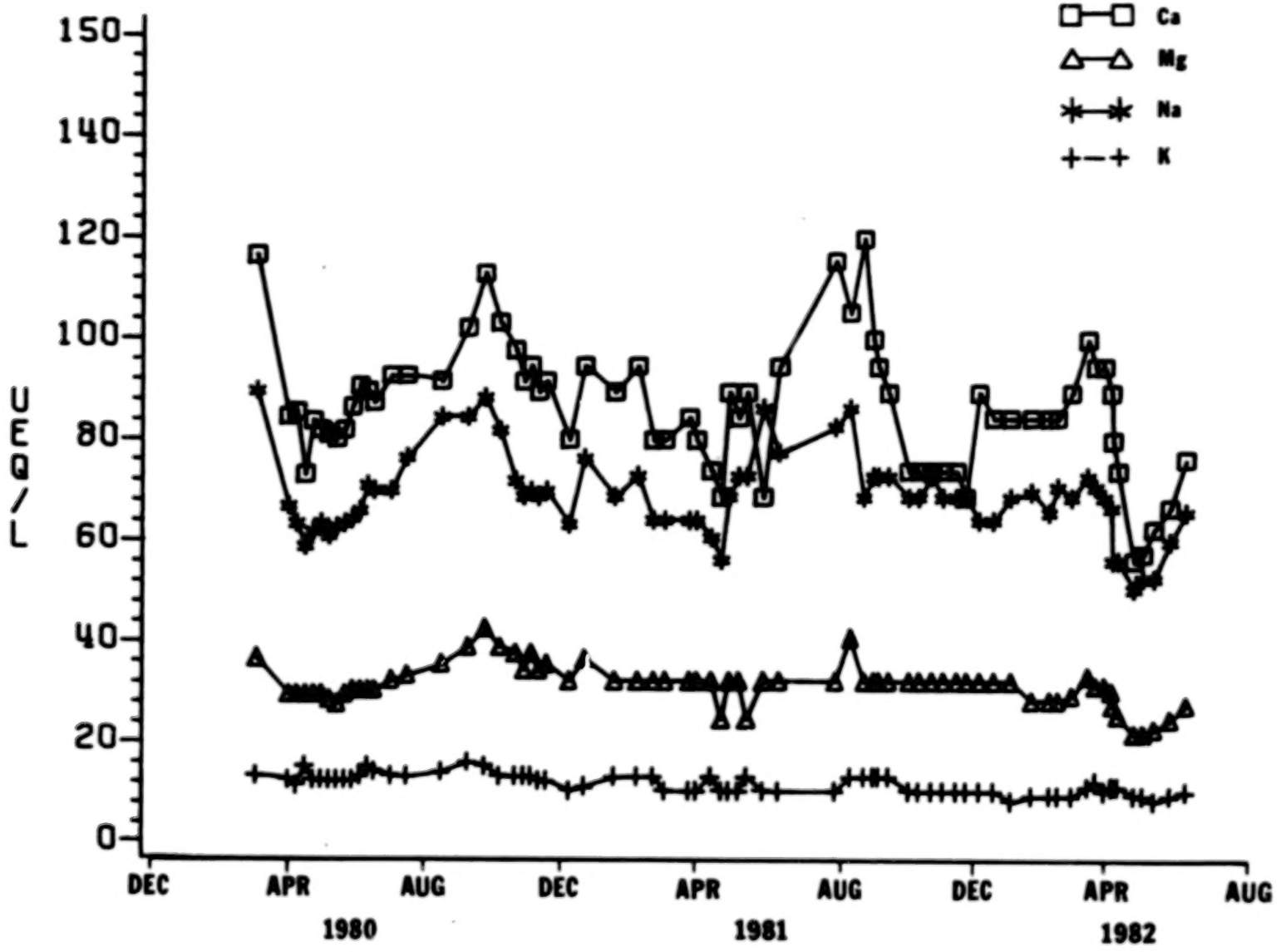

Figure 17. Variations of total concentrations of base cations over time for the Machias River.

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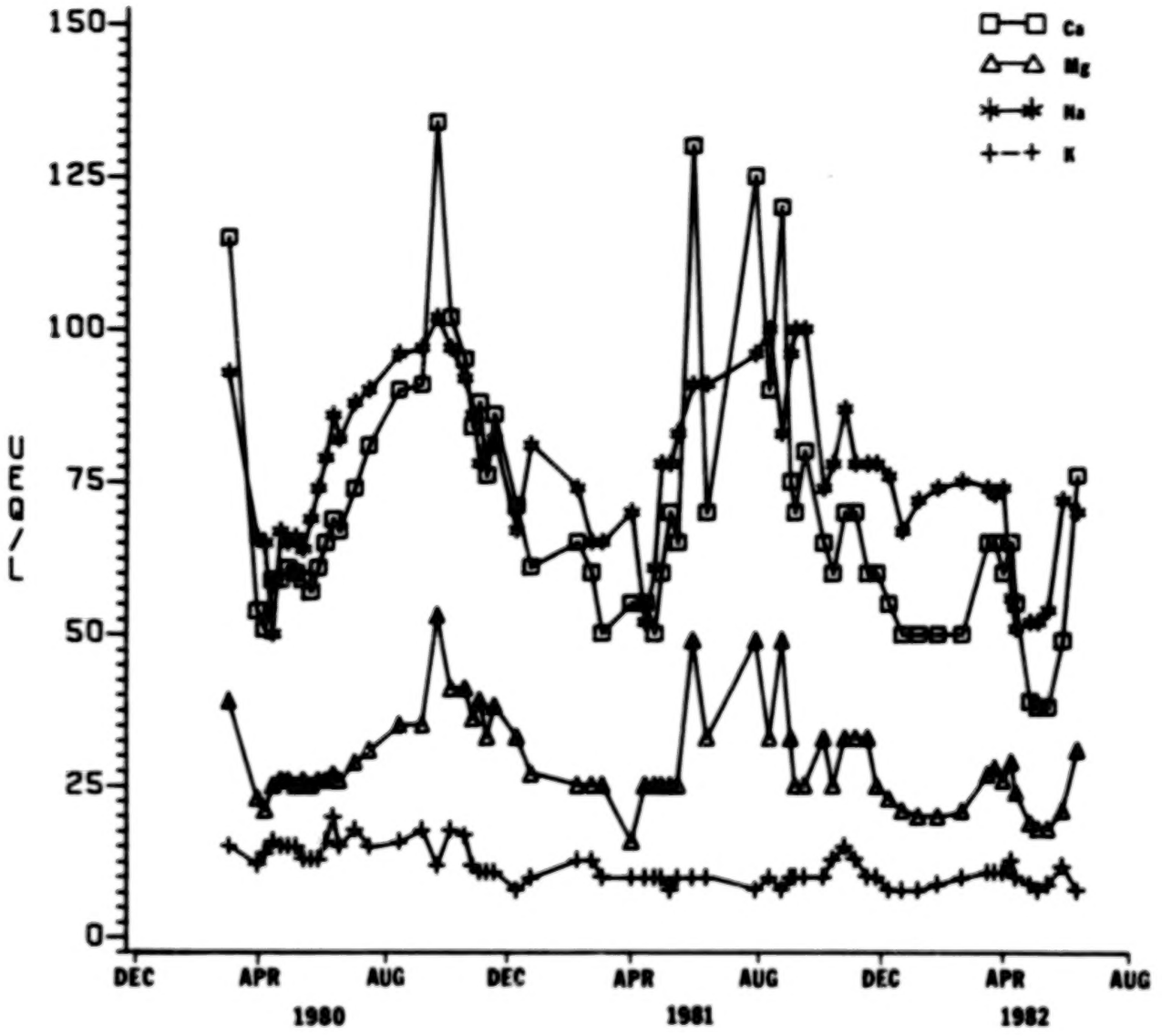

Figure 18. Variations of total concentrations of base cations over time for Kerwin Brook.

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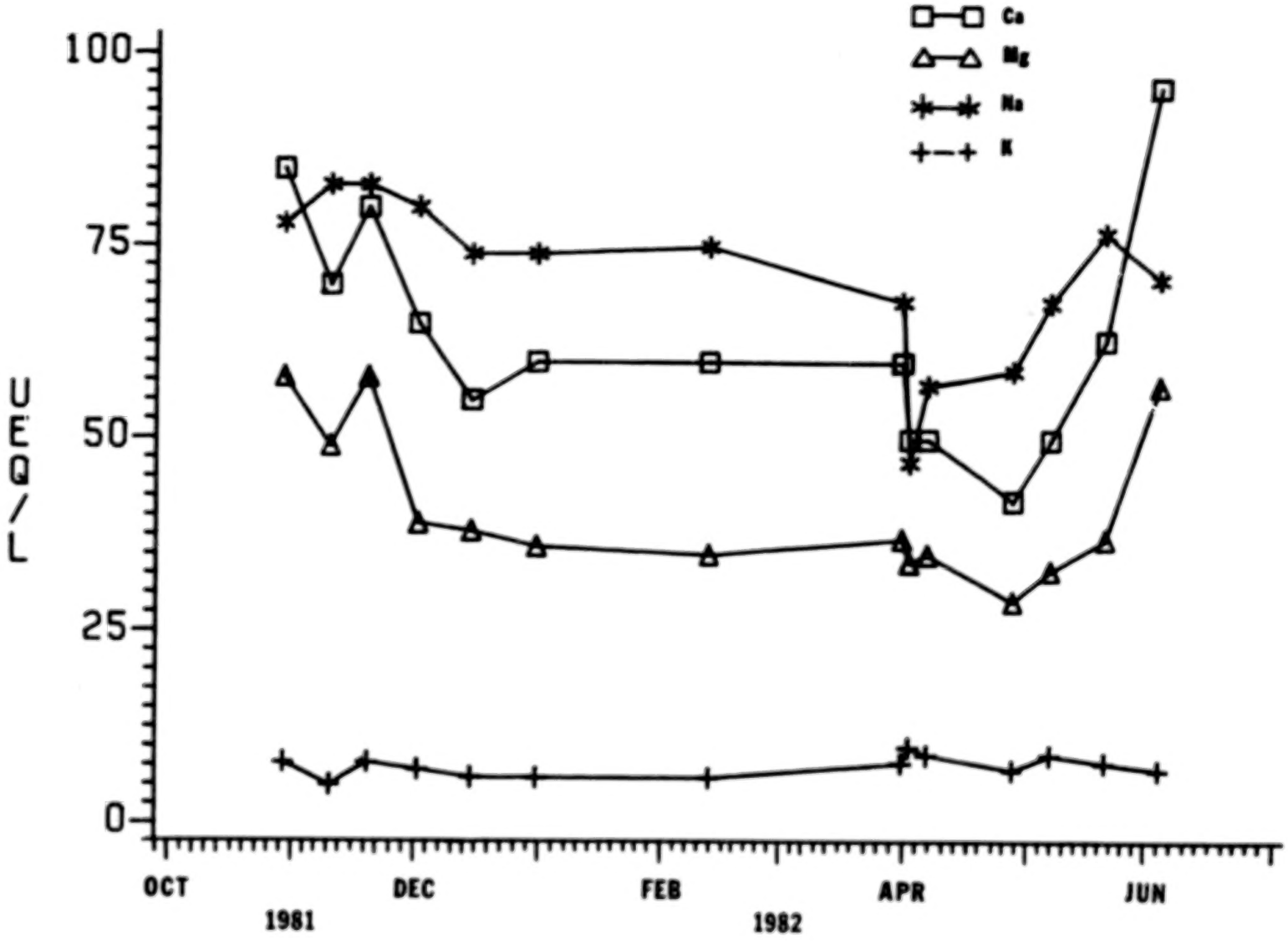

Figure 19. Variations of total concentrations of base cations over time for Holmes Brook.

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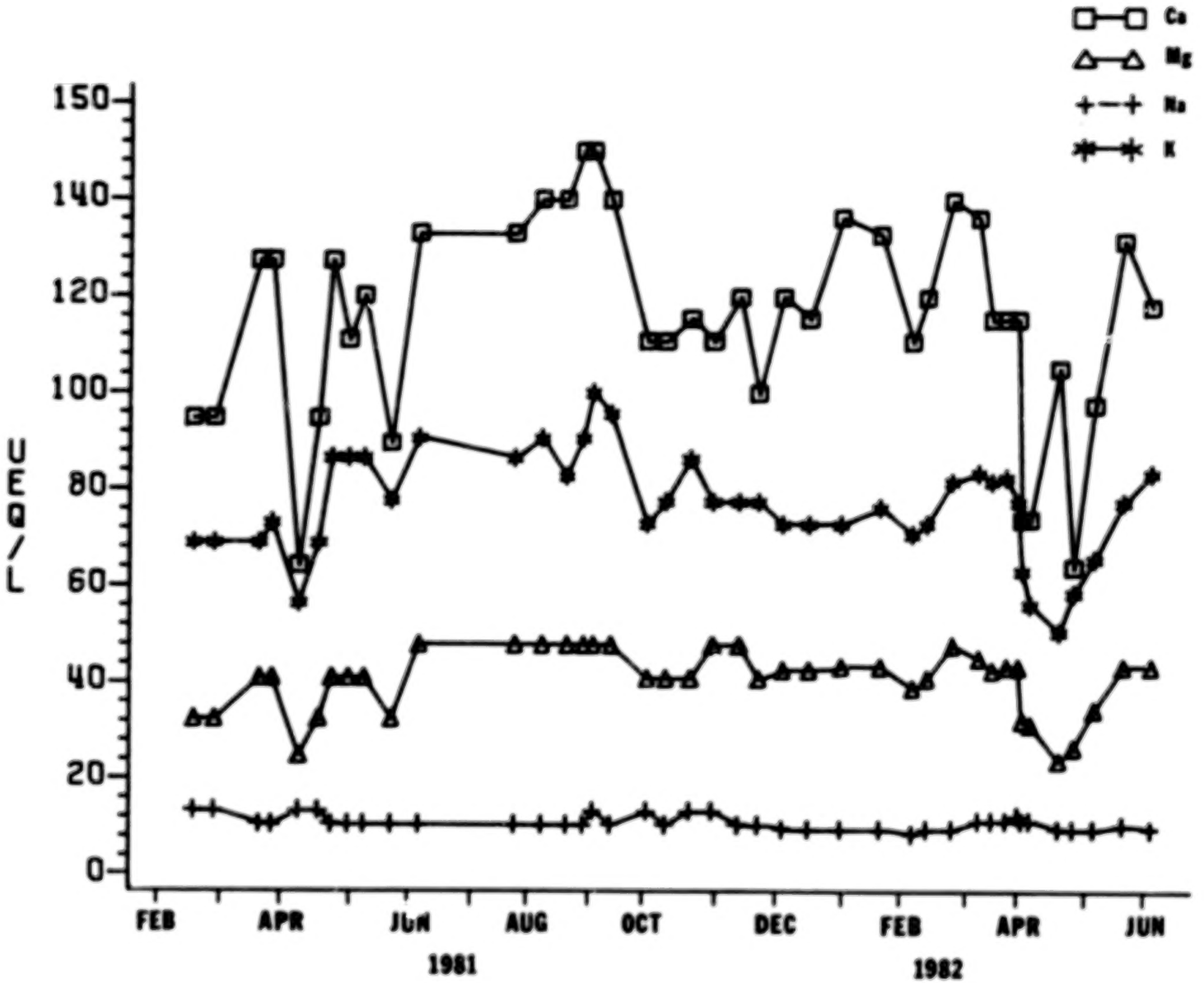

Figure 20. Variations of total concentration of base cations over time for Old Stream.

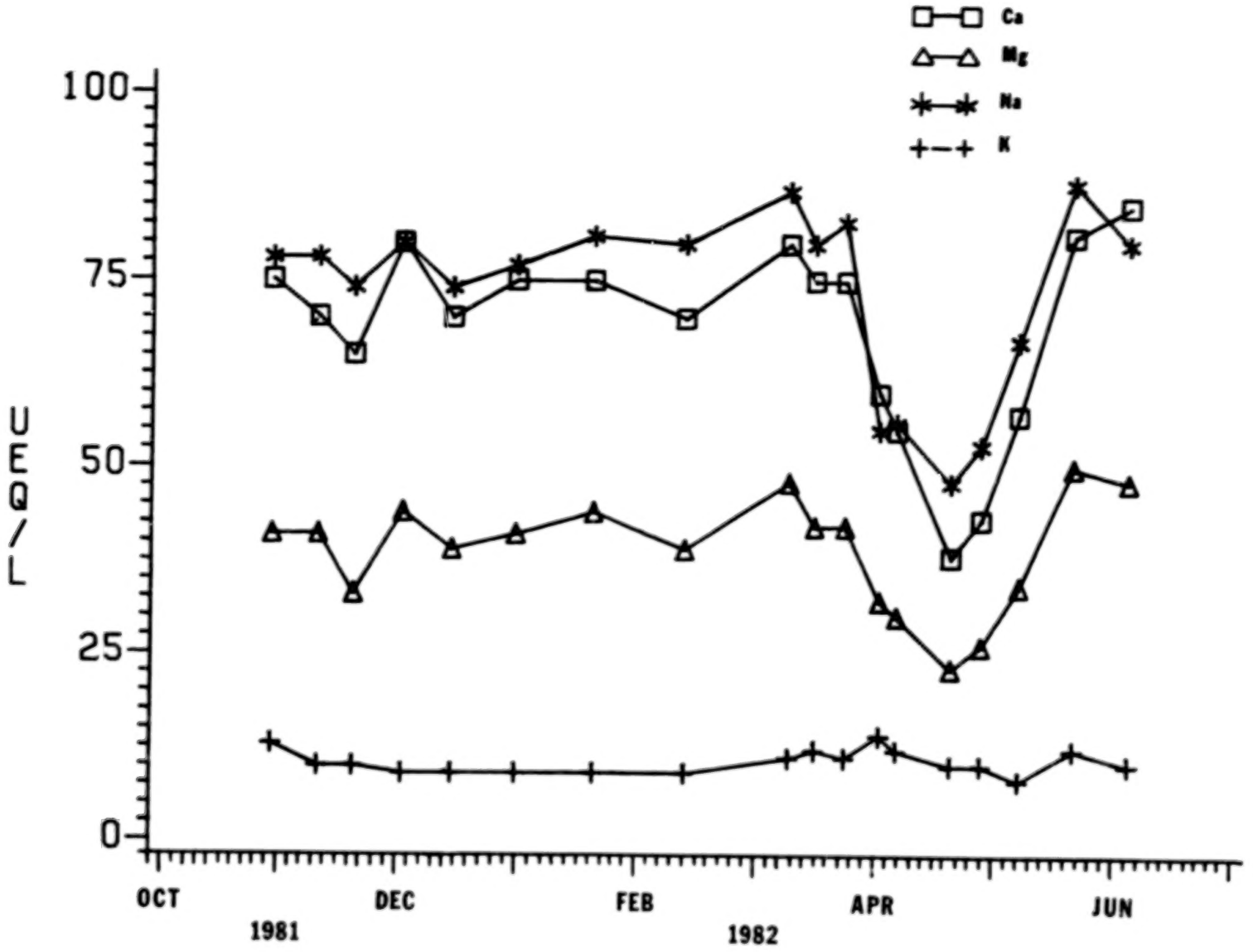

Figure 21. Variations of total concentrations of base cations over time for Bowles Brook.

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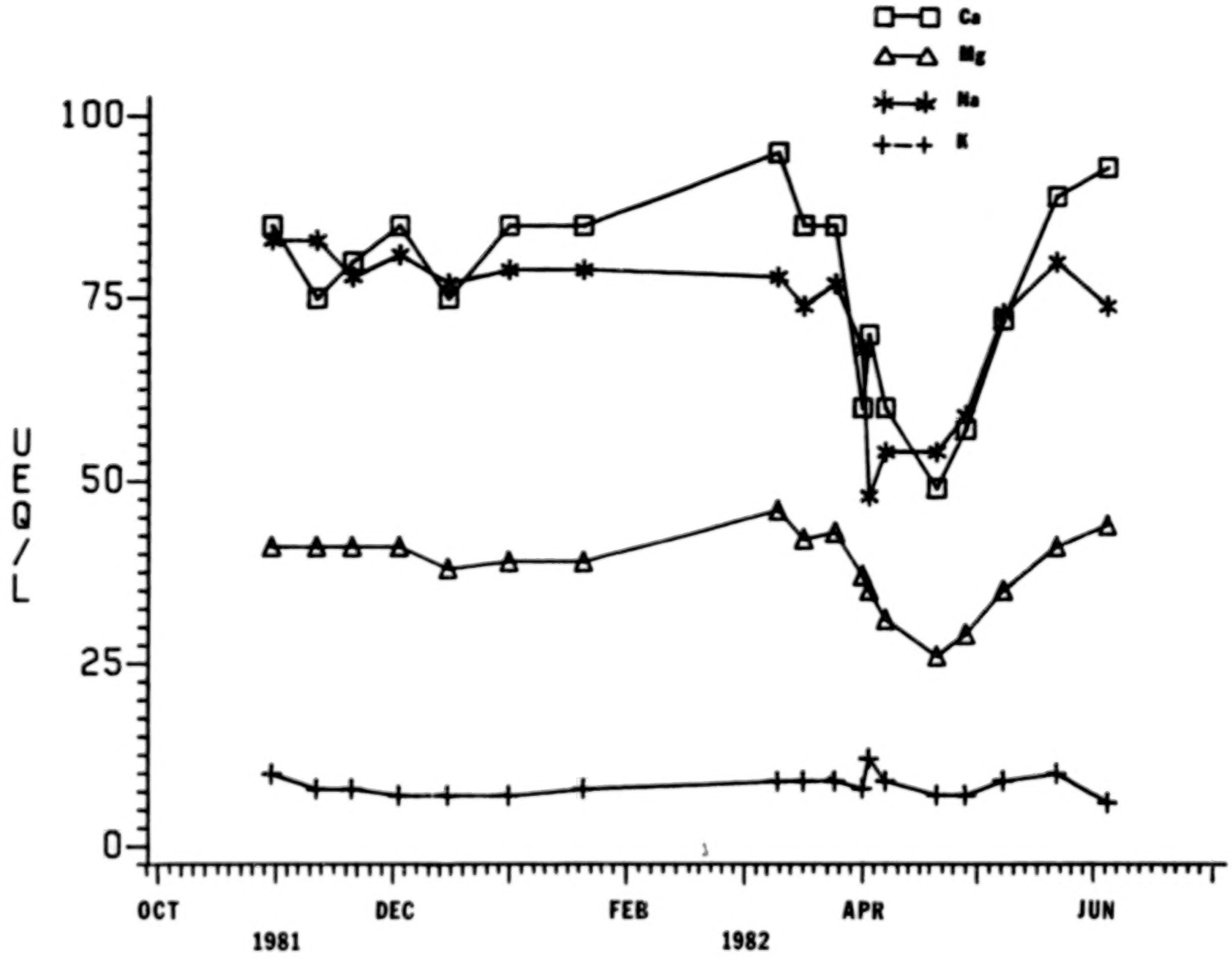

Figure 22. Variations of total concentrations of base cations over time for Harmon Brook.

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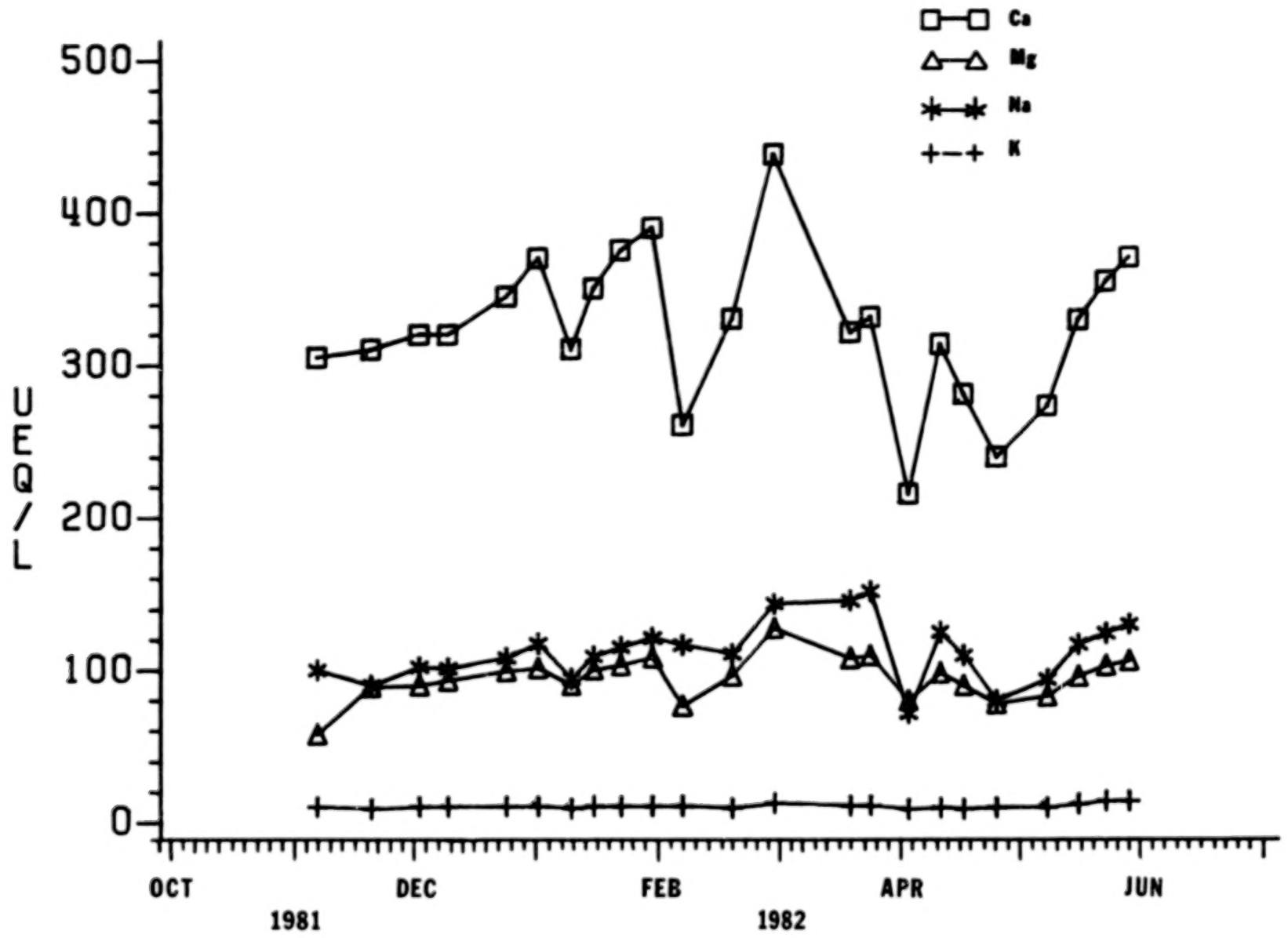

Figure 23. Variations of total concentrations of base cations over time for the White River.

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Anions

The most abundant anions in all streams were bicarbonate, sulfate, and chloride (Table 6). Organic anions were intermediate in concentration in all streams except the White River, where they were very low. Nitrate was low in all streams except the White River, where it was intermediate. Fluoride was very low in all streams.

Few anions other than alkalinity (bicarbonate) were correlated with discharge (Table 5), although the sum of all anions was negatively correlated. Both sulfate and nitrate (Figures 24-32) showed a tendency to reach a peak concentration in March of 1981, preceeding the discharge peak in April (Figure 4) and coinciding with the period of snowmelt (Table 4). The nitrate peak was variable, sometimes sharp and sometimes broad. The timing of the nitrate peak was somewhat later in the White River.

Chloride concentrations were highly variable. Generally there were multiple chloride peaks, usually in the fall and again in late spring, after peak discharge. Chloride concentrations were often stable during winter. Organic anions usually reached their maximum concentration in fall. There often also was a small peak coinciding with peak discharge in April. Organic anions were very low and stable in the White River. Fluoride concentrations were low and stable in all streams.

Ion Correlations

Simple product moment correlations were calculated for pH, alkalinity, and all cations and anions. The number of significant ($p \leq 0.05$) correlations out of the nine correlations for each pair, and the direction of these correlations, were charted as an index of the overall significance of each possible correlation (Table 7). Five or more significant correlations of the same direction were judged indicative of a strong relationship. There were 13 such strong relationships out of 66 possible. Alkalinity was positively related to calcium, magnesium, and sodium, and negatively related to aluminum. The relationships for pH were positive with alkalinity and sodium, and negative with aluminum. Calcium was positively related to magnesium and sodium. There were four other strong relationships, all positive: magnesium with sodium, sodium with fluoride, chloride with sulfate, and aluminum with organic anions.

Ion Discharge

Two rivers studied (Narraguagus and White) were gauged and discharge records were available to enable calculation of discharge of major ions. Precipitation input data for major ions were also available from National Atmospheric Deposition Program stations at Acadia National Park, Maine, (47 km from Narraguagus River) and Hubbard Brook, New Hampshire (76 km from White River). The input and output of total ions were calculated on an areal basis (Table 8). Total ions input from precipitation were estimated by multiplying wet deposition by 1.5 (Wright and Johannessen 1980). Both river systems discharged more calcium and magnesium than were input from precipitation, but less hydrogen ion. Potassium was nearly balanced at both sites, with input approximately the same as output. Sodium was nearly balanced in the Narraguagus but there was an excess of discharge in the

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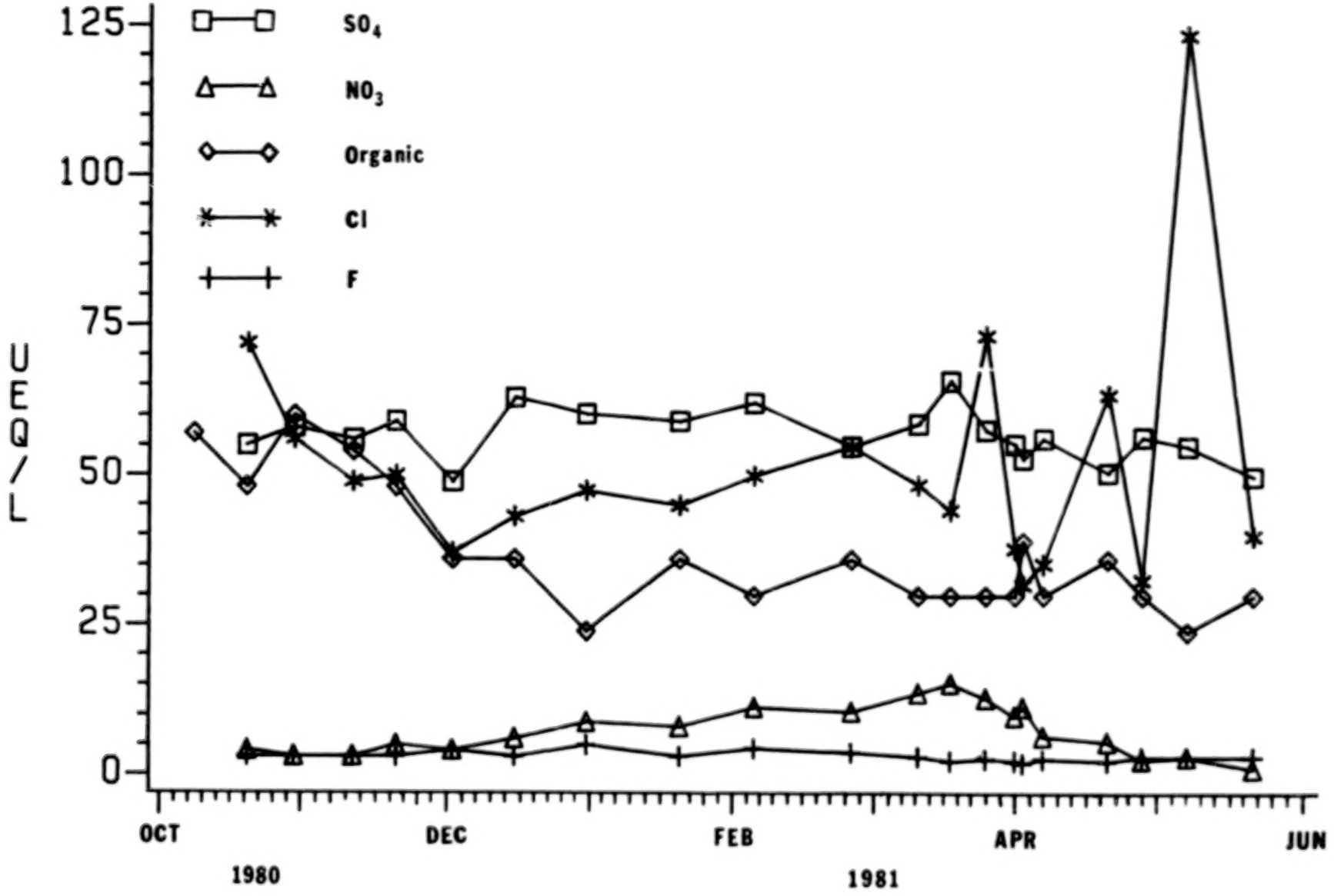

Figure 24. Variations of total concentrations of major anions over time for the Narraguagus River.

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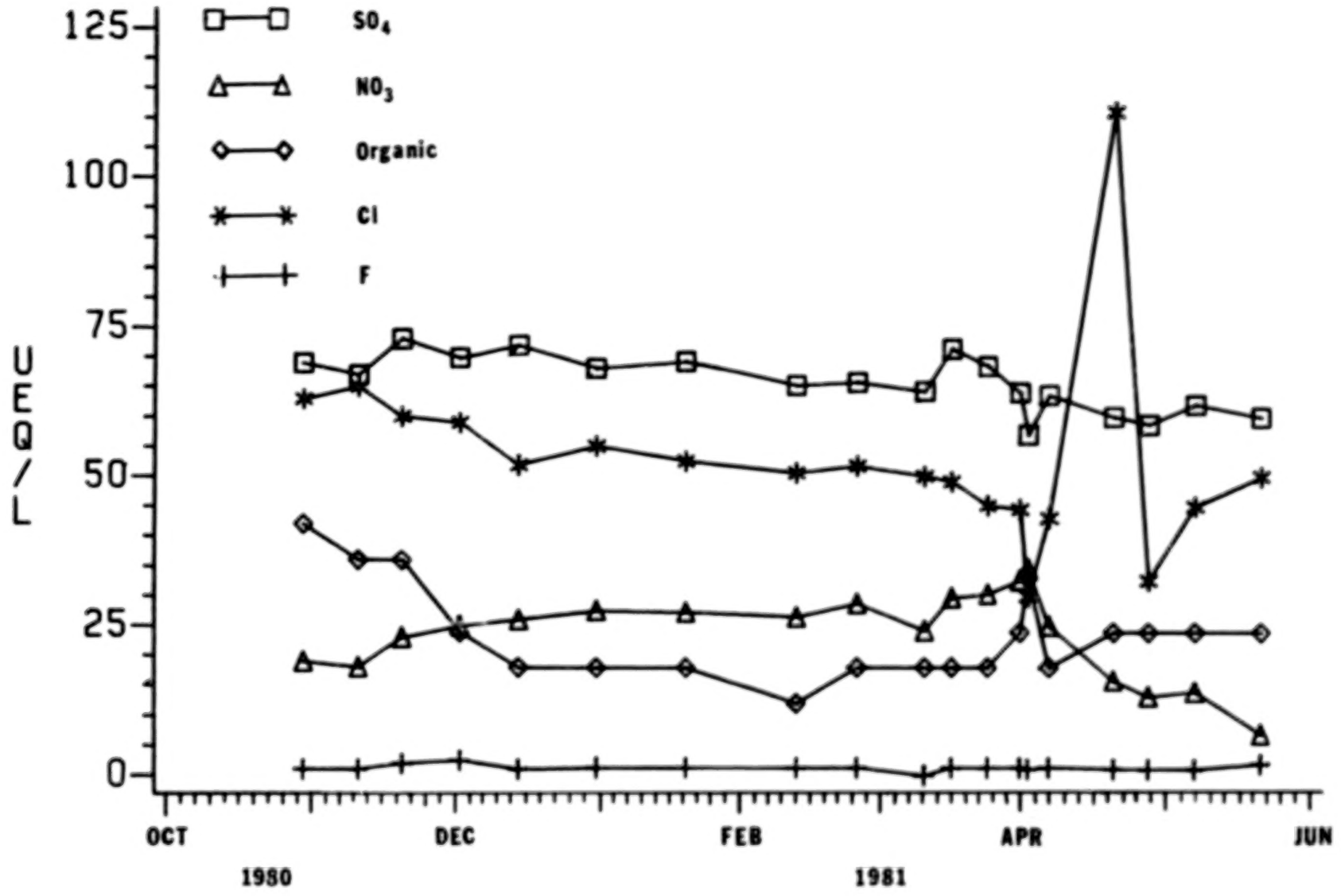

Figure 25. Variations of total concentrations of major anions over time for Sinclair Brook.

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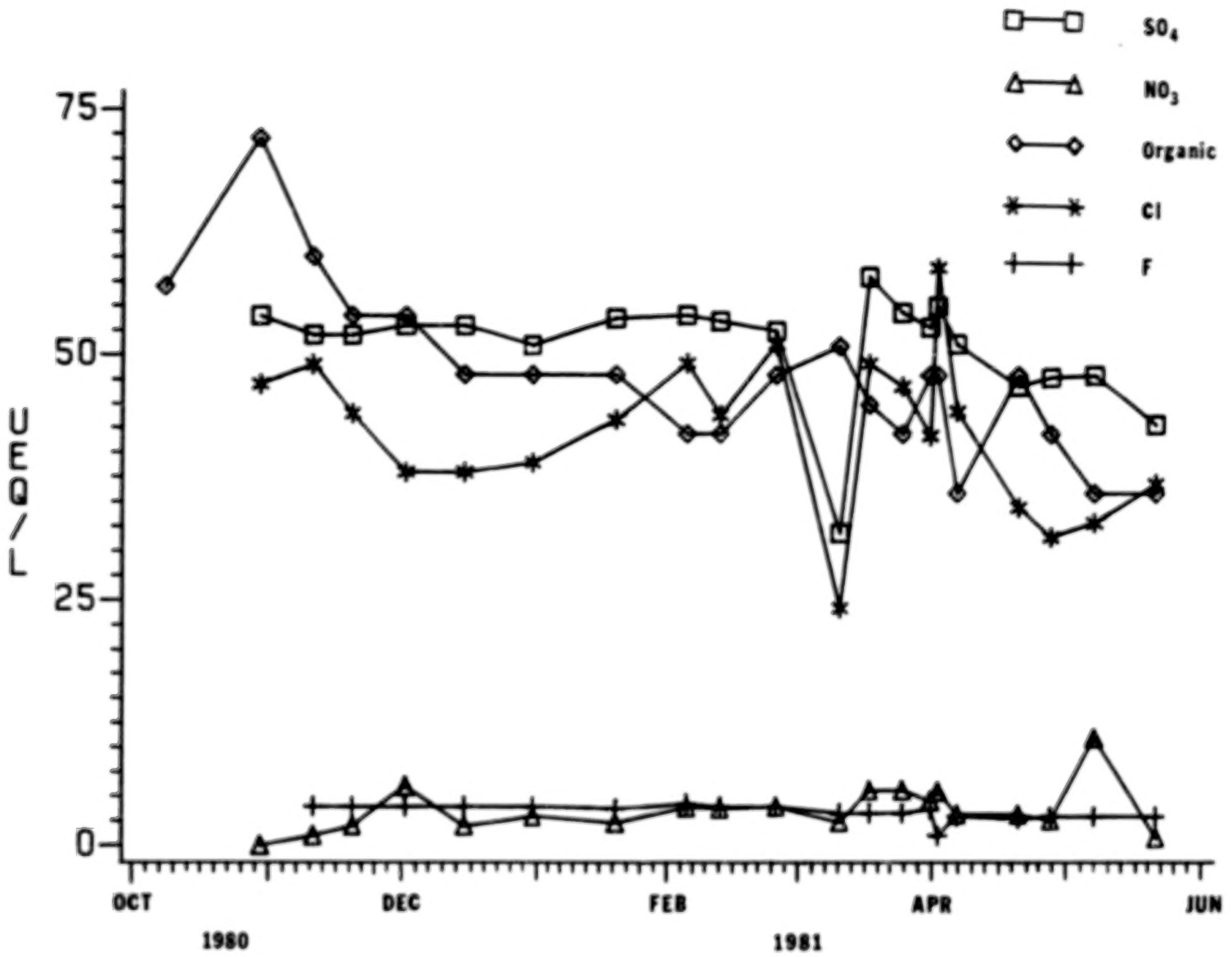

Figure 26. Variations of total concentrations of major anions over time for the Machias River.

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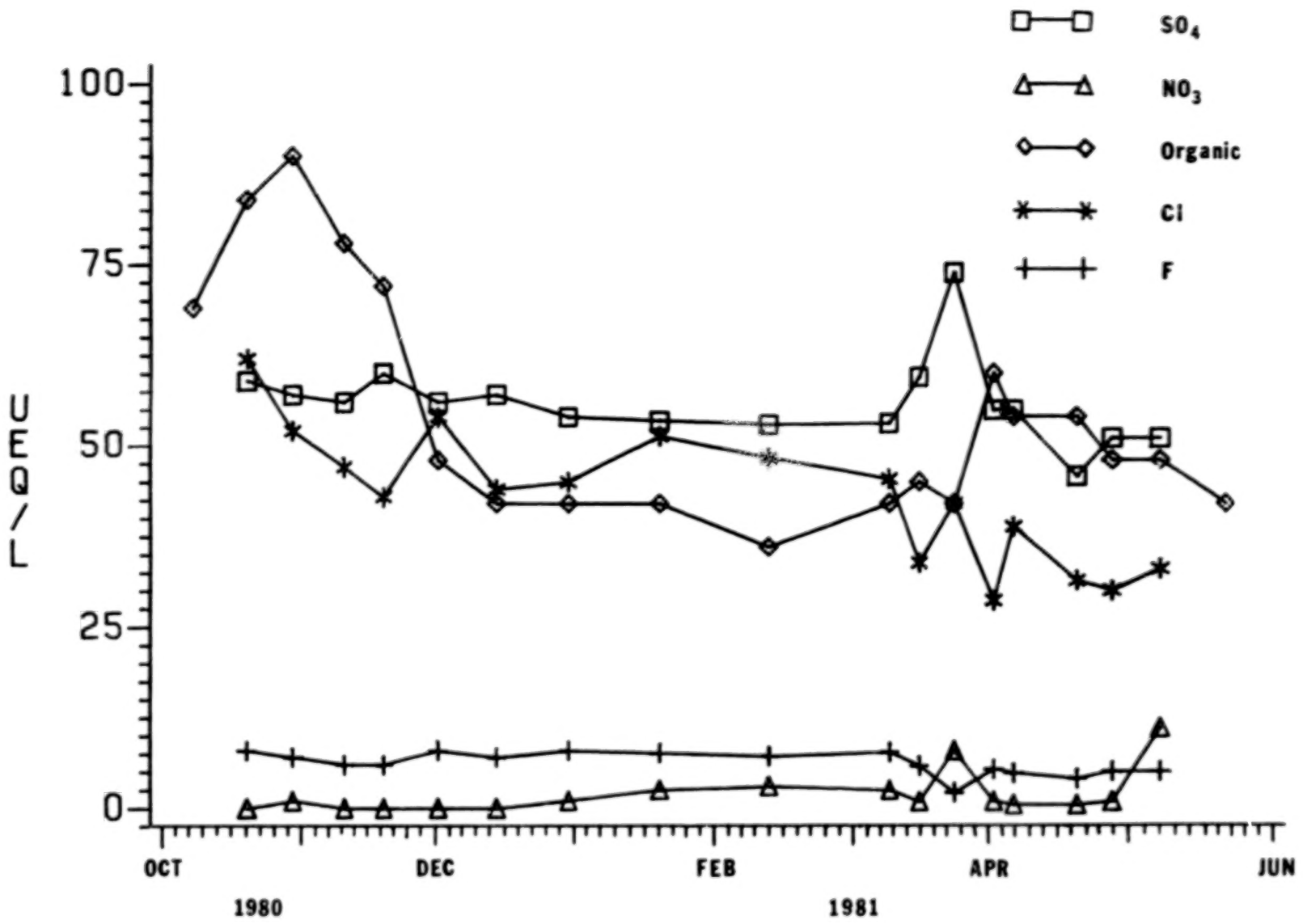

Figure 27. Variations of total concentrations of major anions over time for Kerwin Brook.

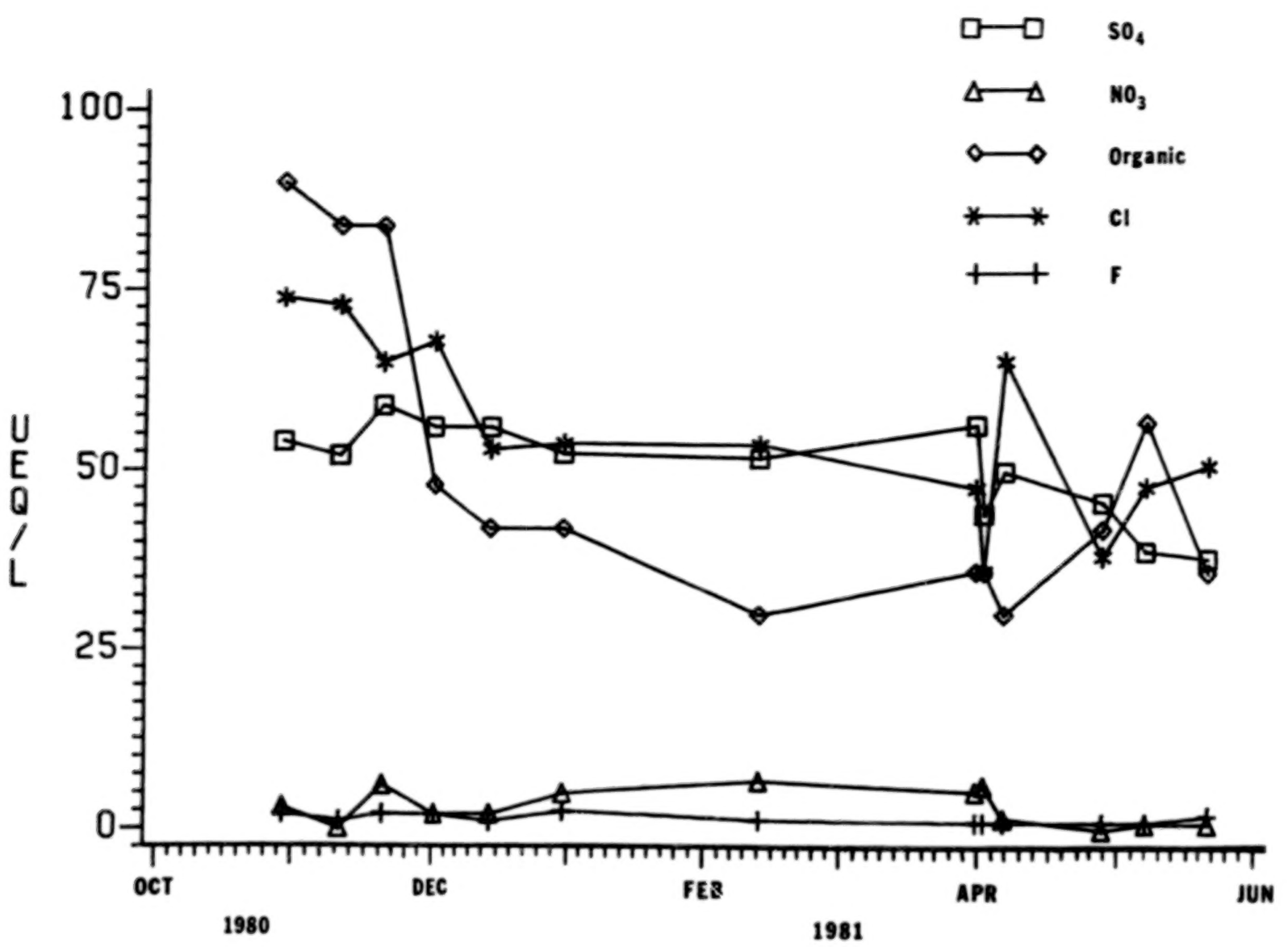

Figure 28. Variations of total concentrations of major anions over time for Holmes Brook.

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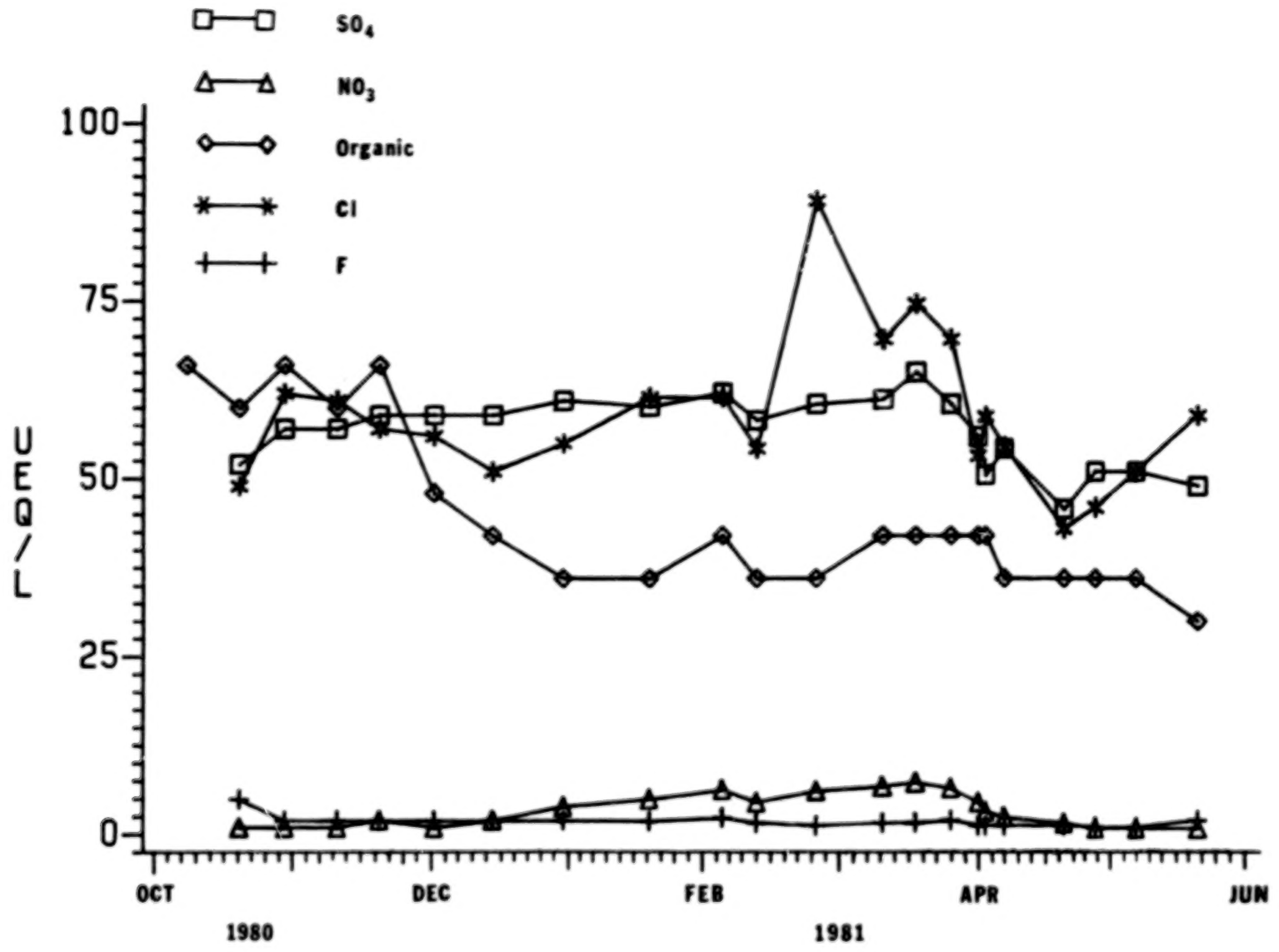

Figure 29. Variations of total concentrations of major anions over time for Old Stream.

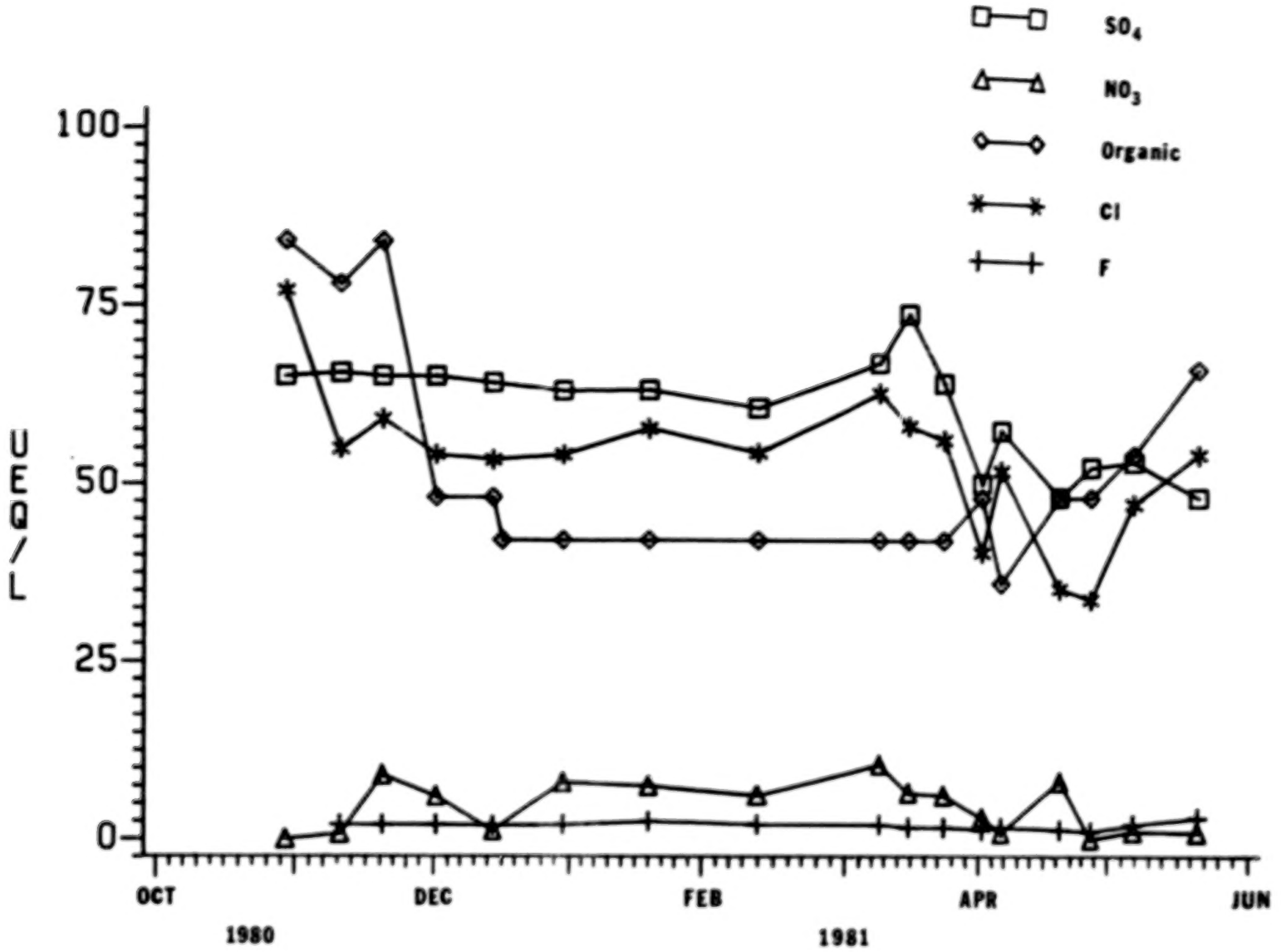

Figure 30. Variations of total concentrations of major anions over time for Bowles Brook.

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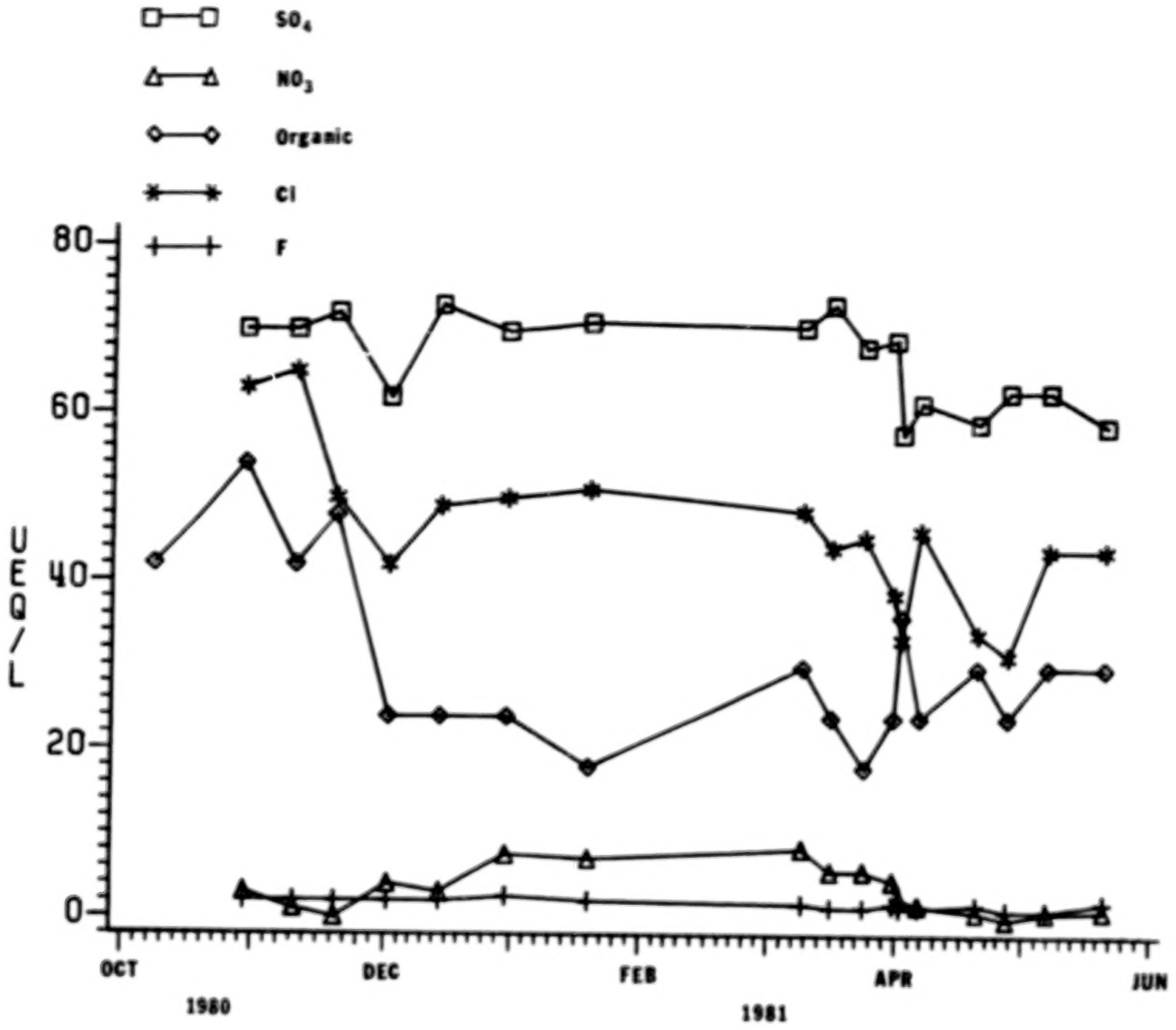

Figure 31. Variations of total concentrations of major anions over time for Harmon Brook.

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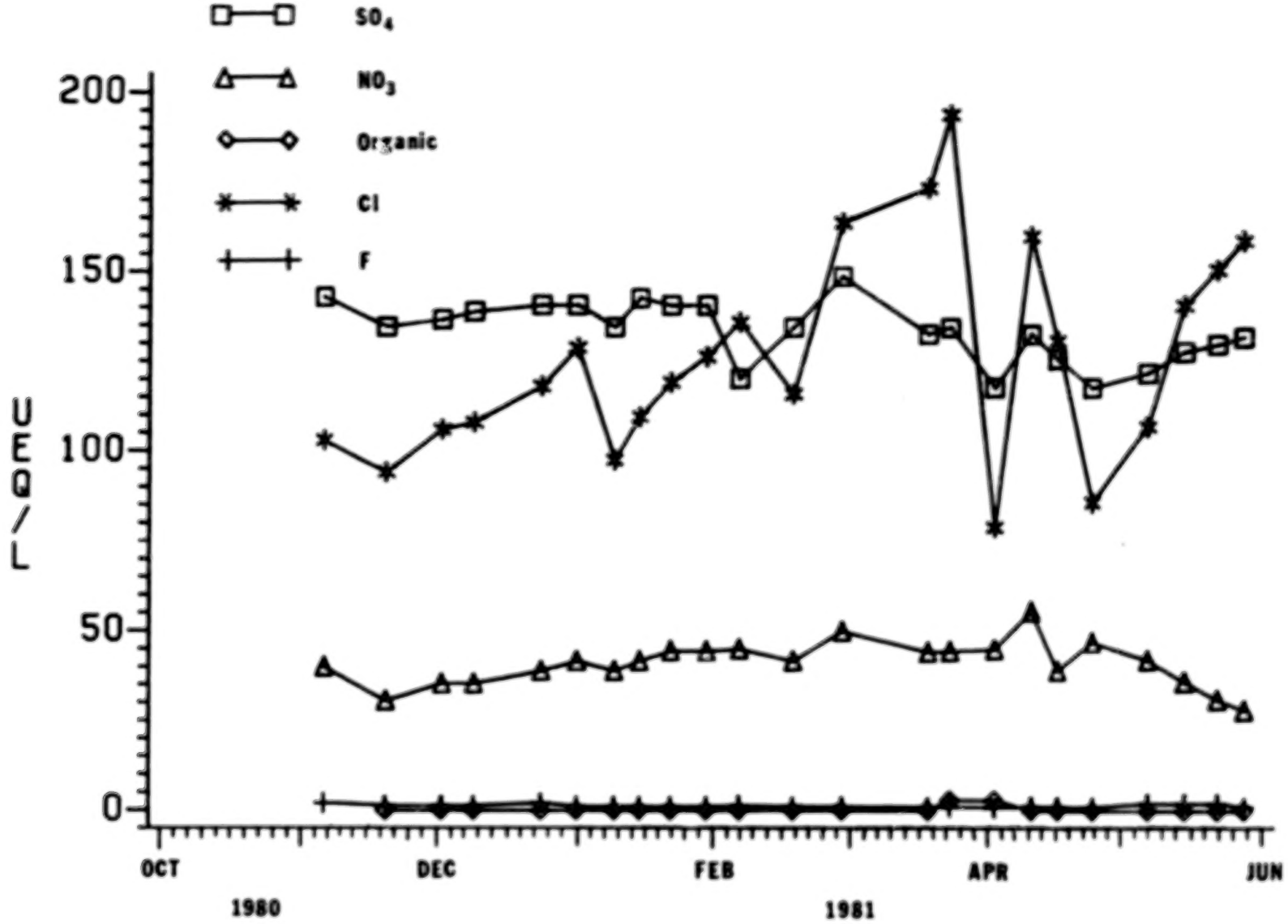

Figure 32. Variations of total concentrations of major anions over time for the White River.

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Table 7. Number and direction of significant ($p \leq 0.05$) correlation coefficients among the ions measured.

	pH	alkalinity	calcium	magnesium	sodium	potassium	chloride	nitrate	sulfate	aluminum	fluoride	organic anions
pH	-	9+	4+	4+	7+	3+	0	1-	1+	5-	1+	3-
alkalinity	-	-	7+	6+	6+	2+ 2-	1+	0	1+	5-	3+	3-
calcium	-	-	-	9+	9+	2+	3+	1+	2+	2+ 1-	2+	2+
magnesium	-	-	-	-	9+	2+	3+	0	2+	2+	2+	4+
sodium	-	-	-	-	-	3+	3+ 2-	0	3+	1+	5+	2+
potassium	-	-	-	-	-	-	1+	0	0	3+	1-	2-
chloride	-	-	-	-	-	-	-	1+	5+	0	2+	0
nitrate	-	-	-	-	-	-	-	-	4+	0	0	2-
sulfate	-	-	-	-	-	-	-	-	-	1-	0	2-
aluminum	-	-	-	-	-	-	-	-	-	-	1-	9+
fluoride	-	-	-	-	-	-	-	-	-	-	-	1+

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Table 8. Precipitation input, discharge output, and net retention (input-output) of major ions for the Narraguagus and White rivers. Units are meq/m^2/year except as noted.

	Narraguagus R.				White R.			
	precipitation		discharge	net retention	precipitation		discharge	net retention
	wet	total			wet	total		
Ca	7	11	130	-119	5	8	182	-174
Mg	16	24	46	-22	3	5	67	-62
Na	61	92	88	4	3	5	86	-81
K	2	3	18	-15	0	0	8	-8
H	33	50	~1	49	34	51	<1	51
Σ cations	119	179	284	-105	45	68	343	-275
HCO_3	0	0	87	-87	0	0	162	-162
SO_4	44	66	81	-15	33	50	106	-56
NO_3	15	23	10	13	21	32	35	-3
Cl	72	108	61	47	4	6	99	-93
Organic anion	0	0	59	-59	0	0	<1	~0
Σ anions	130	195	298	-103	58	87	403	-316
water (mm)		1,048	768	-280		886	626	-256

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White River. Inputs were relatively similar at the two sites for calcium, magnesium, and hydrogen ion, but sodium and potassium were much higher at the Narraguagus. Discharge of calcium, magnesium, and sodium were highest in the White River.

Discharge of sulfate and chloride were higher than precipitation input for the White River. The Narraguagus River retained chloride, and sulfate was nearly balanced. Nitrate was nearly balanced in both rivers. Bicarbonate discharge exceeds precipitation input, which is negligible for this ion, for both rivers. Discharge of all anions, including nitrate, was higher in the White River than in the Narraguagus River. Precipitation input of chloride was highest in the Narraguagus River. Sulfate input was also higher in the Narraguagus River, as was hydrogen ion, but nitrate input was lower.

The ionic balance of both discharge output and precipitation input was reasonably good. The cation denudation rate (CDR) for each of the gauged rivers, defined as the discharge of non-marine cations excluding hydrogen ion per unit watershed area, was 215 meq/m^2/yr for the Narraguagus River and 232 meq/m^2/yr for the White River. The contribution of cations from precipitation is negligible, except for hydrogen ion. The CDR model of Thompson (1982) predicts a pH of 6.27 for the Narraguagus River and 6.51 for the White River. The CDR model as presented ignores nitrate, which was significant in the White River. If nitrate is included in the model the predicted pHs are 6.24 and 6.39 respectively. The actual volume weighted mean pH was 6.02 for the Narraguagus River and 6.92 for the White River.

Intragravel Water

Intragravel water samples were very difficult to collect under the conditions experienced. The standpipes froze, were dislodged by moving ice, and filled with silt. The vacuum tubing froze and the pump clogged with silt. Consequently, few water samples of adequate quality were obtained for analysis: four samples from Bowles Brook and six from Old Stream.

Intragravel pH (Figure 33), alkalinity (Figure 34), and specific conductance (Figure 35) were generally higher than stream values for the same sample dates. Both the stream and intragravel values follow similar seasonal patterns, with no apparent time lag for the intragravel values. Values for Old Stream almost always exceeded those of Bowles Brook. The differences between the two sets of values were smallest during the period of high discharge in April.

Intragravel values of calcium (Figure 36) and aluminum (Figure 37) also generally exceeded stream values. The maximum aluminum concentrations reached in intragravel water samples were as much as 40 times higher than in stream water samples. Sulfate concentrations are slightly higher in the stream than in intragravel water and are slightly higher in Bowles Brook than in Old Stream (Figure 38).

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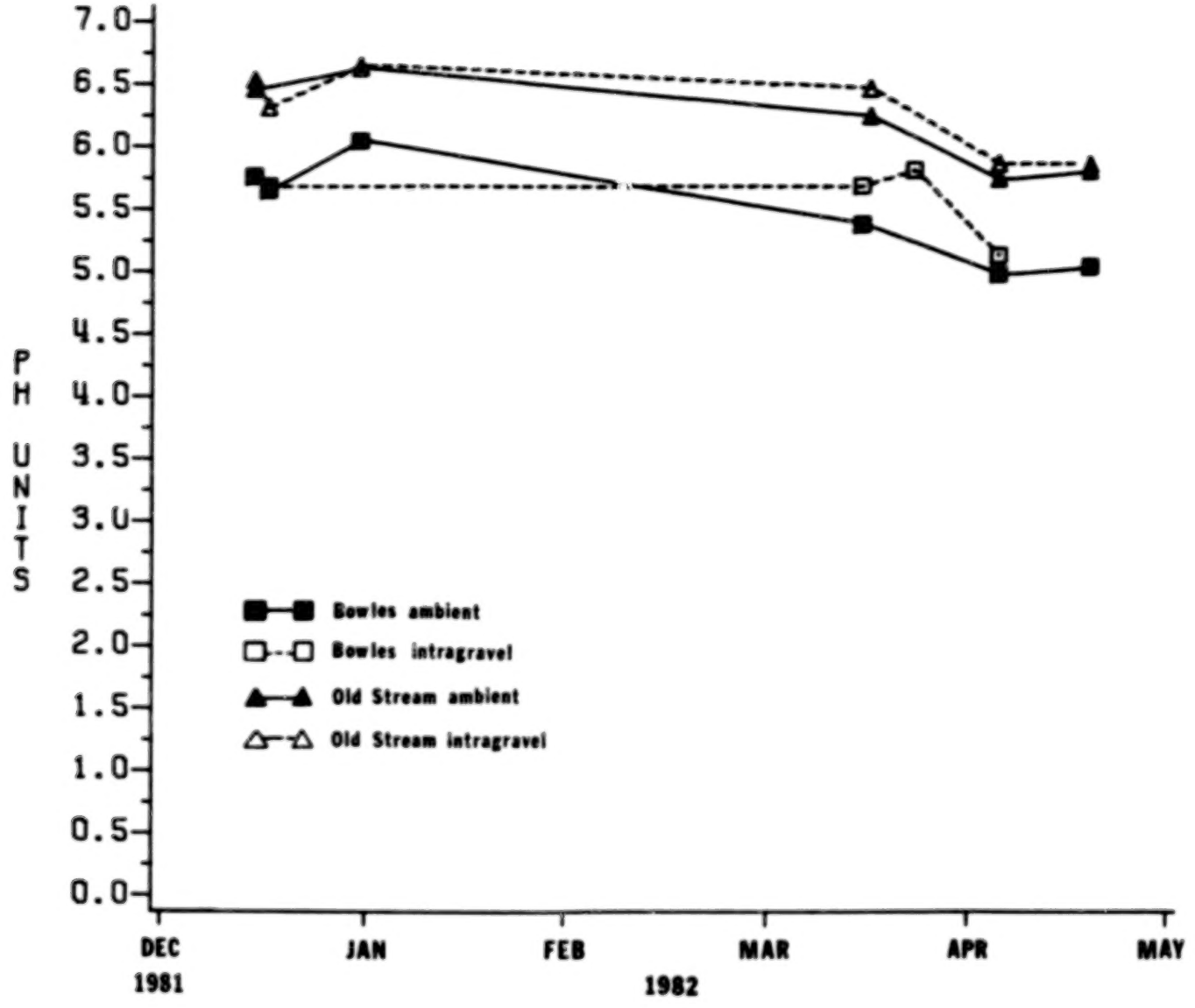

Figure 33. Comparison of pH of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

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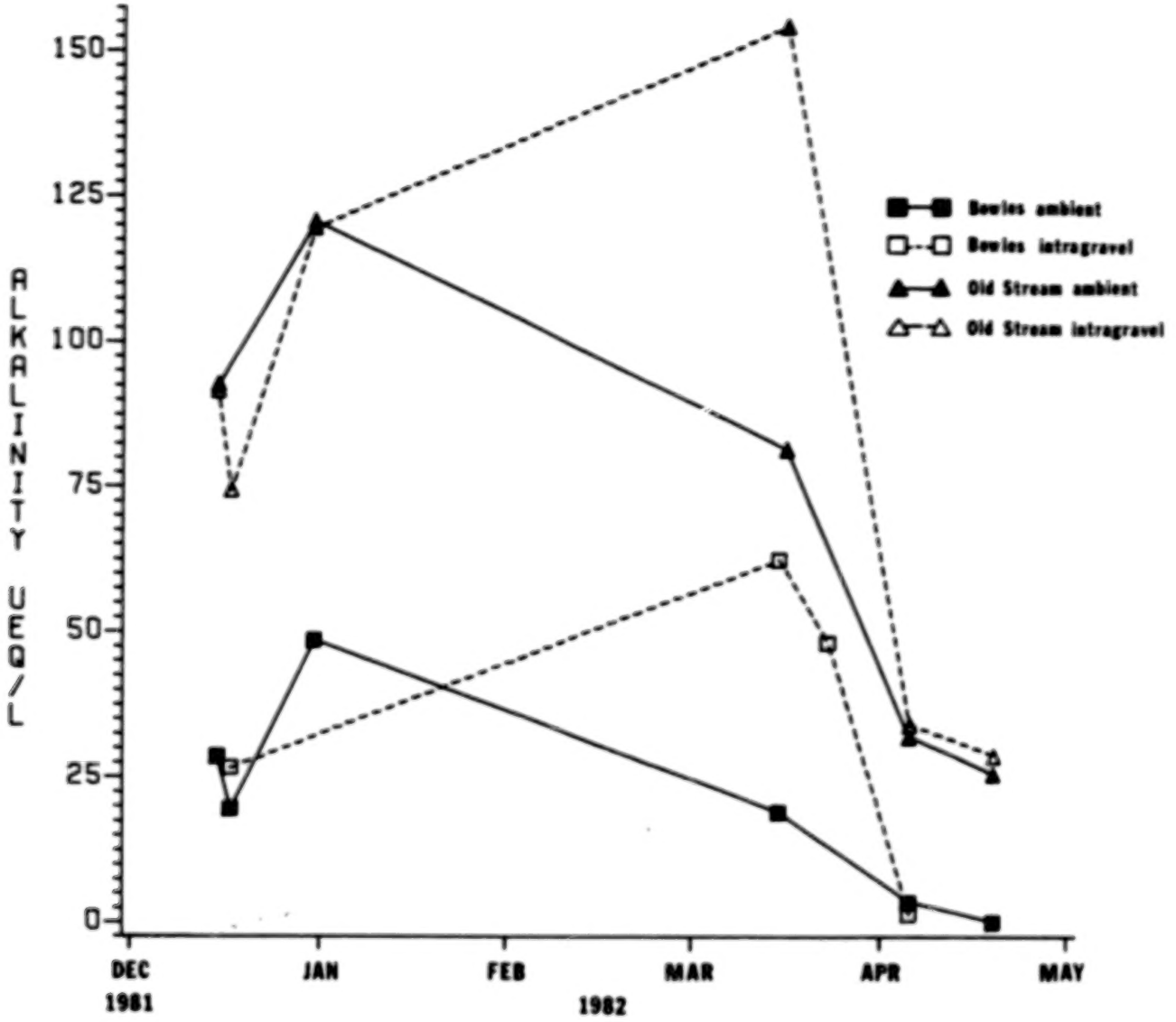

Figure 34. Comparison of alkalinity of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

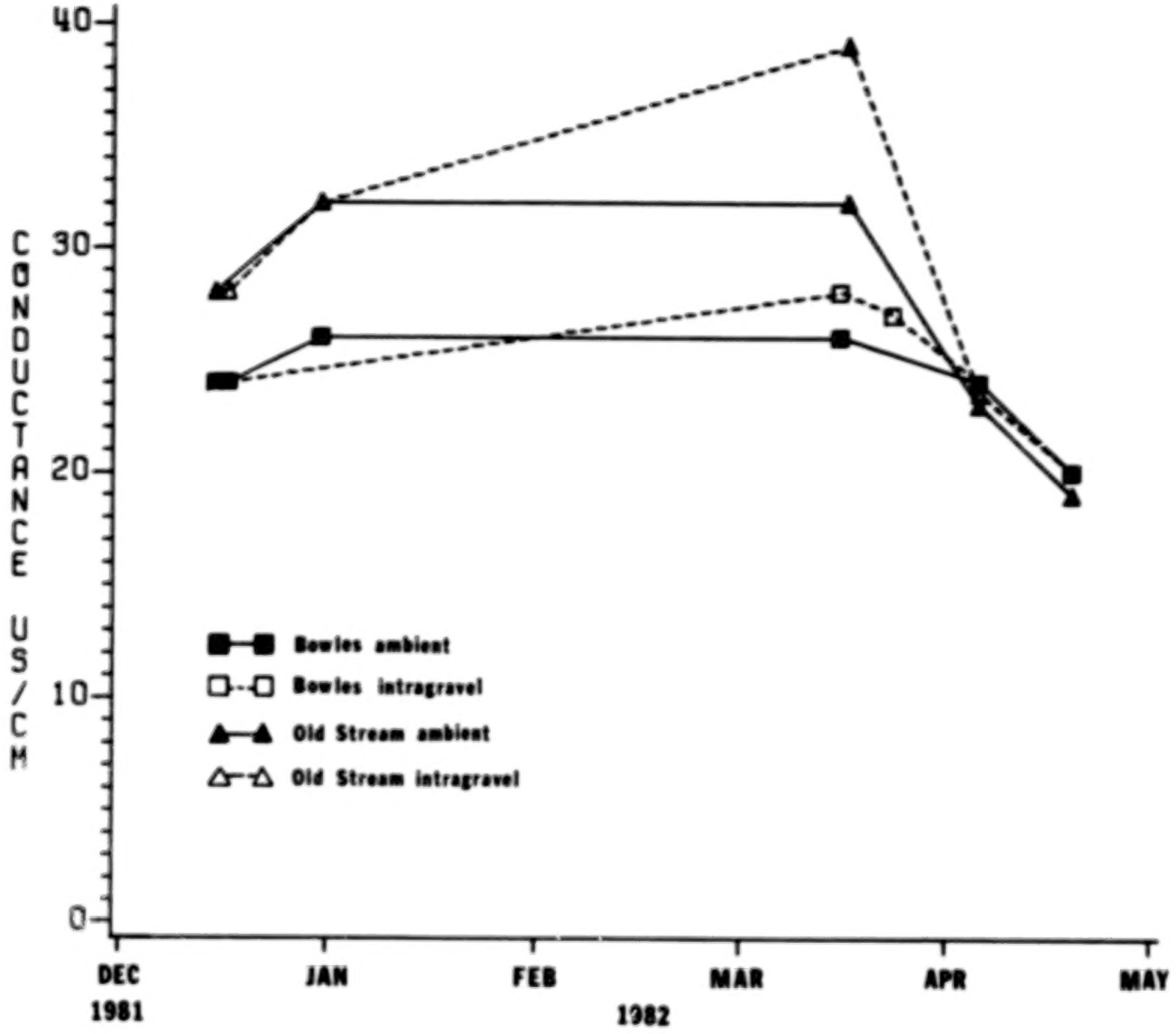

Figure 35. Comparison of specific conductance of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

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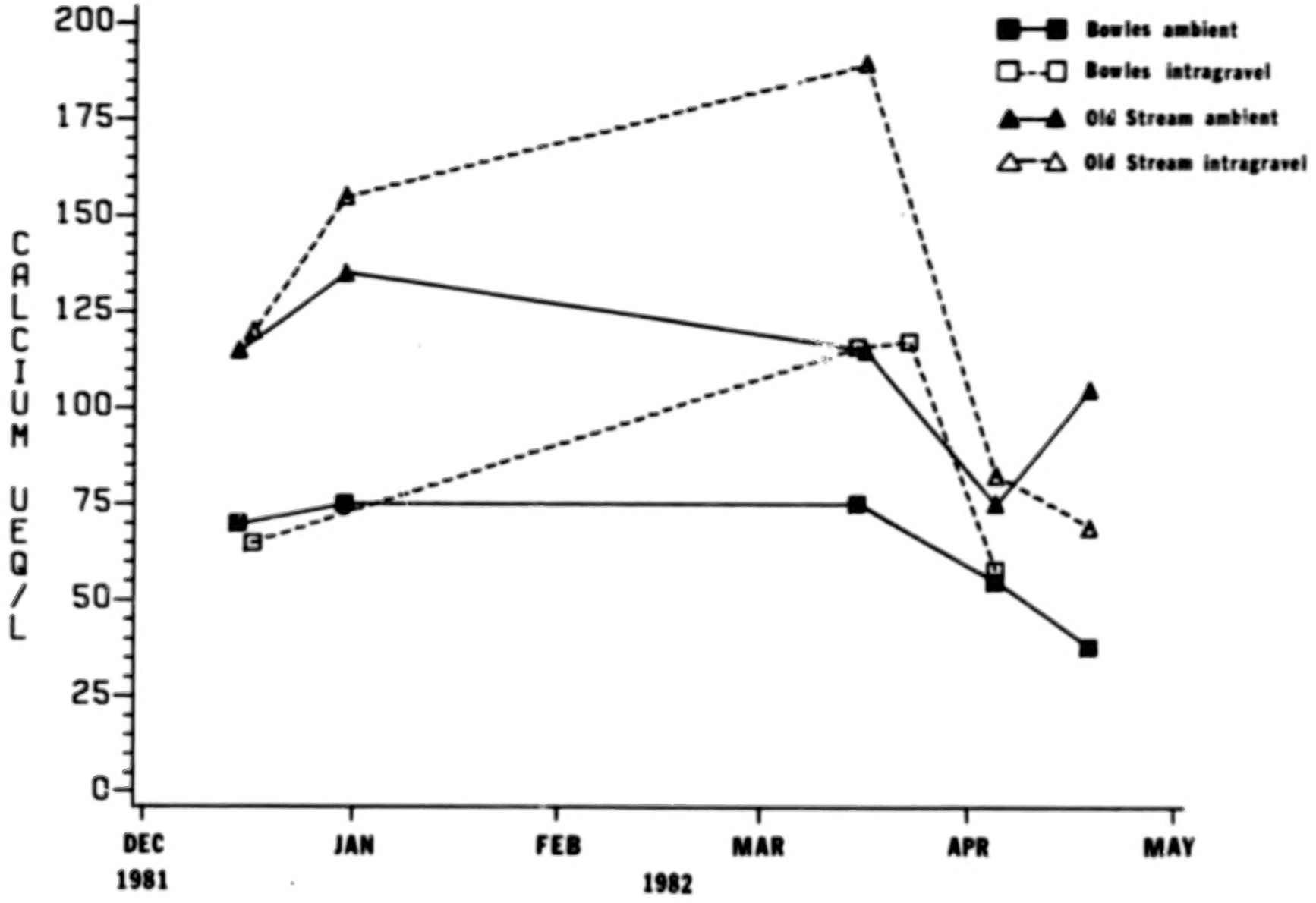

Figure 36. Comparison of calcium concentration of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

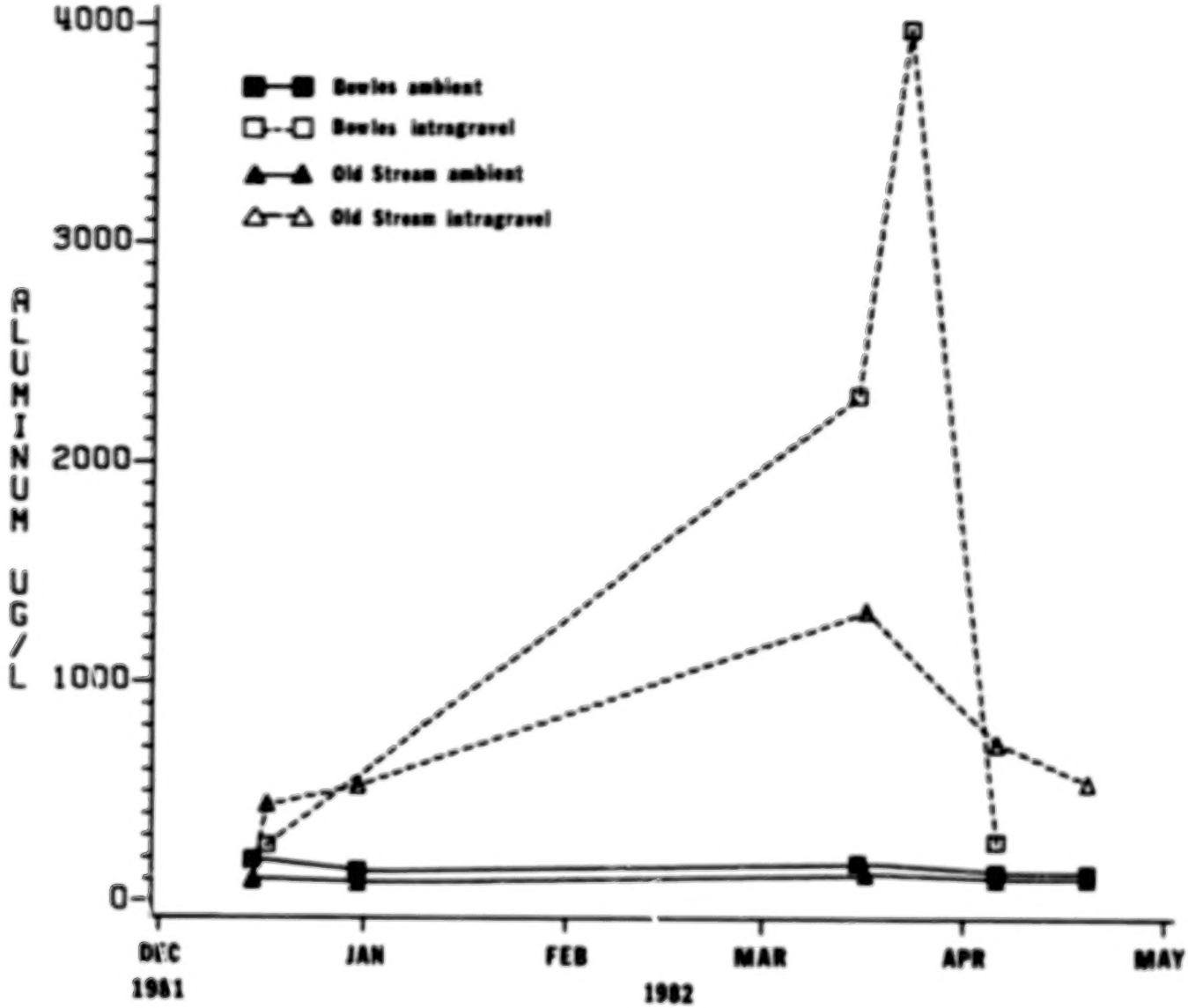

Figure 37. Comparison of aluminum concentration of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

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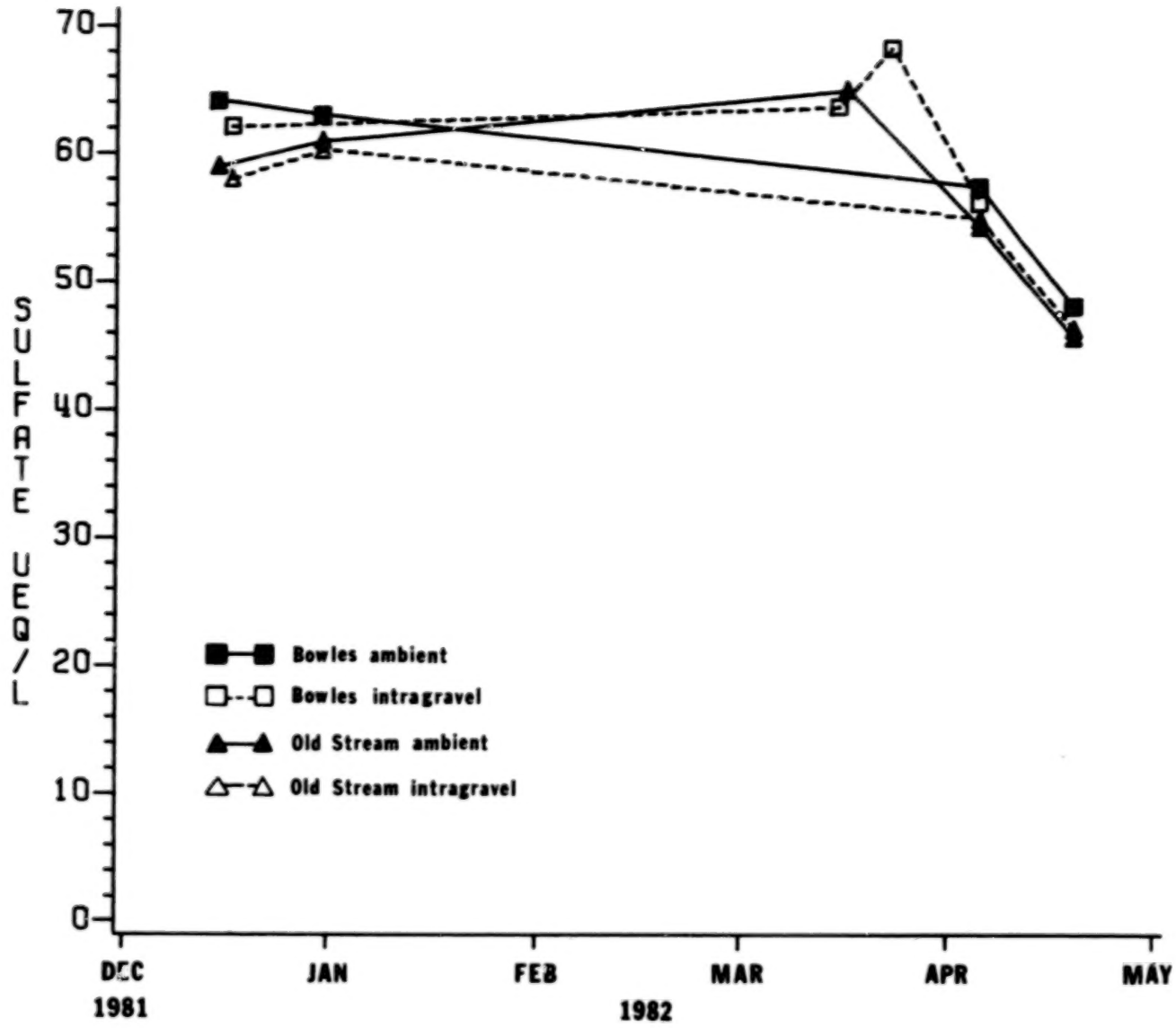

Figure 38. Comparison of sulfate concentration of ambient and intragravel stream water over time for Bowles Brook and Old Stream.

Comparisons with Previous Data

Previous chemistry data were available for the Narraguagus and Machias rivers. Data were available for 10 samples collected nearly monthly from February 1969 to January 1970 (Taylor 1973). The discharge of the Narraguagus River on sample dates in 1969 was similar to that during our sampling period. The mean sample date discharge was 18 m^3/sec in 1969, and 20/m^3/sec in 1981-82. Comparison of pH and alkalinity data from 1980-82 to those of 1969 (Figures 39-42) reveals no apparent differences. The timing of annual cycles is similar and the maxima and minima are also similar. The alkalinity data plotted for 1980-82 are fixed endpoint data, which is what was measured in 1969. Specific conductance (Figures 43-44) appears to have been slightly higher in 1980-82 than in 1969.

The only chemical factor that is markedly different between the historical and recent data is aluminum (Figures 45-46). Total aluminum concentrations were considerably higher for 1980-82, but seasonal patterns were similar. Concentrations in 1980-82 appeared to be higher than in 1969 during periods of high discharge but similar to those in 1969 during periods of low discharge.

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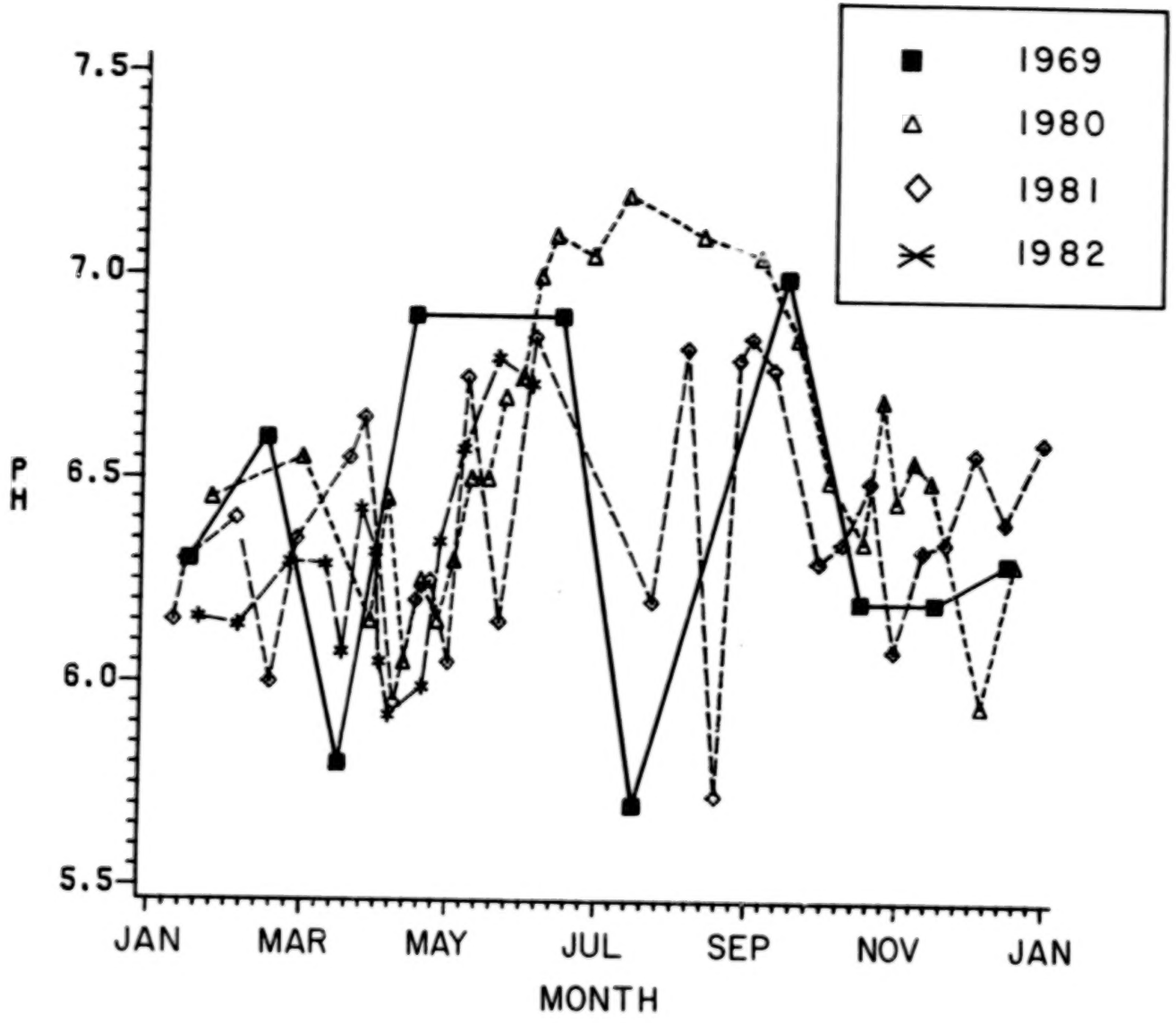

Figure 39. Comparison of recent and previous pH for the Narraguagus River.

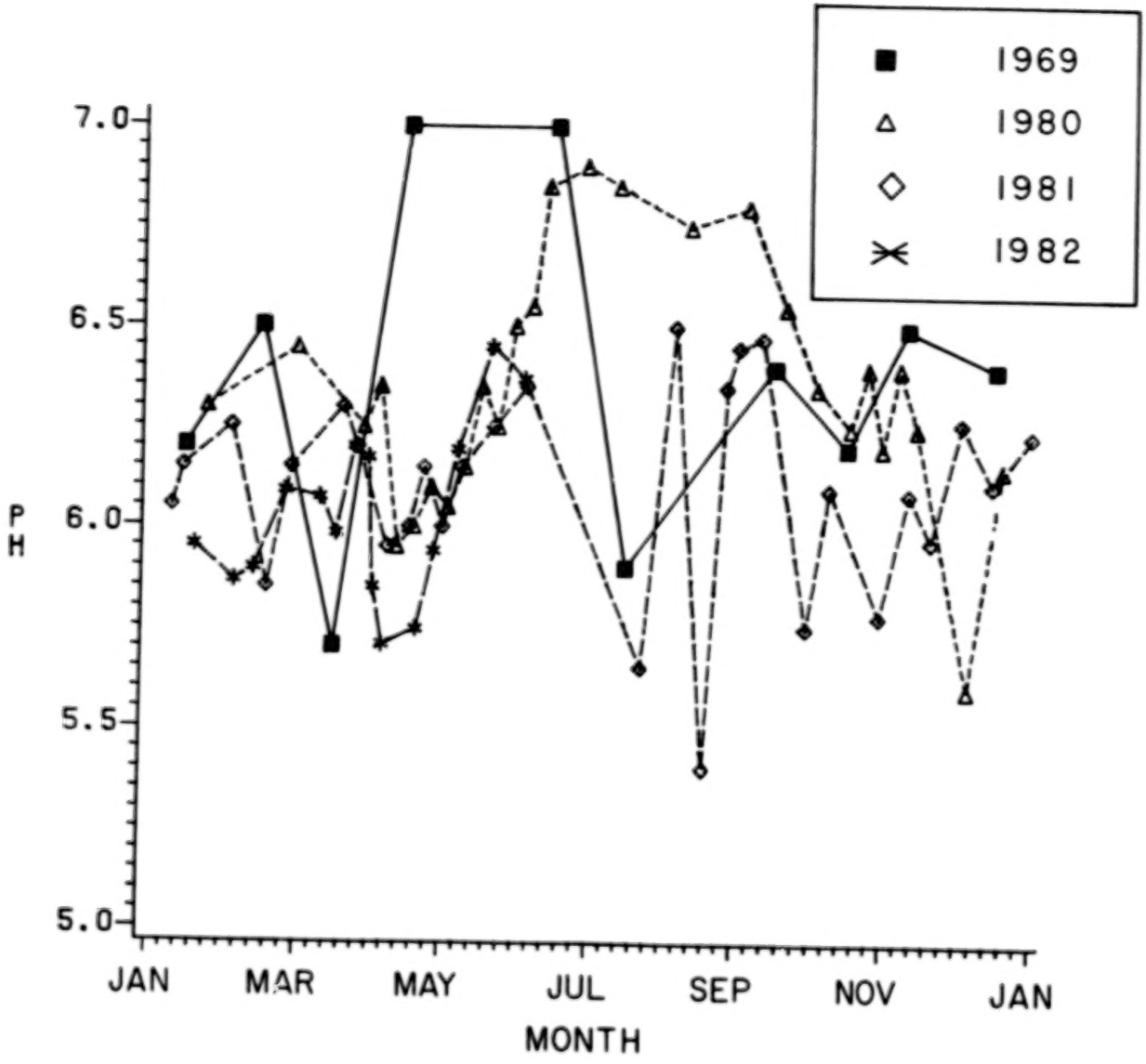

Figure 40. Comparison of recent and previous pH for the Machias River.

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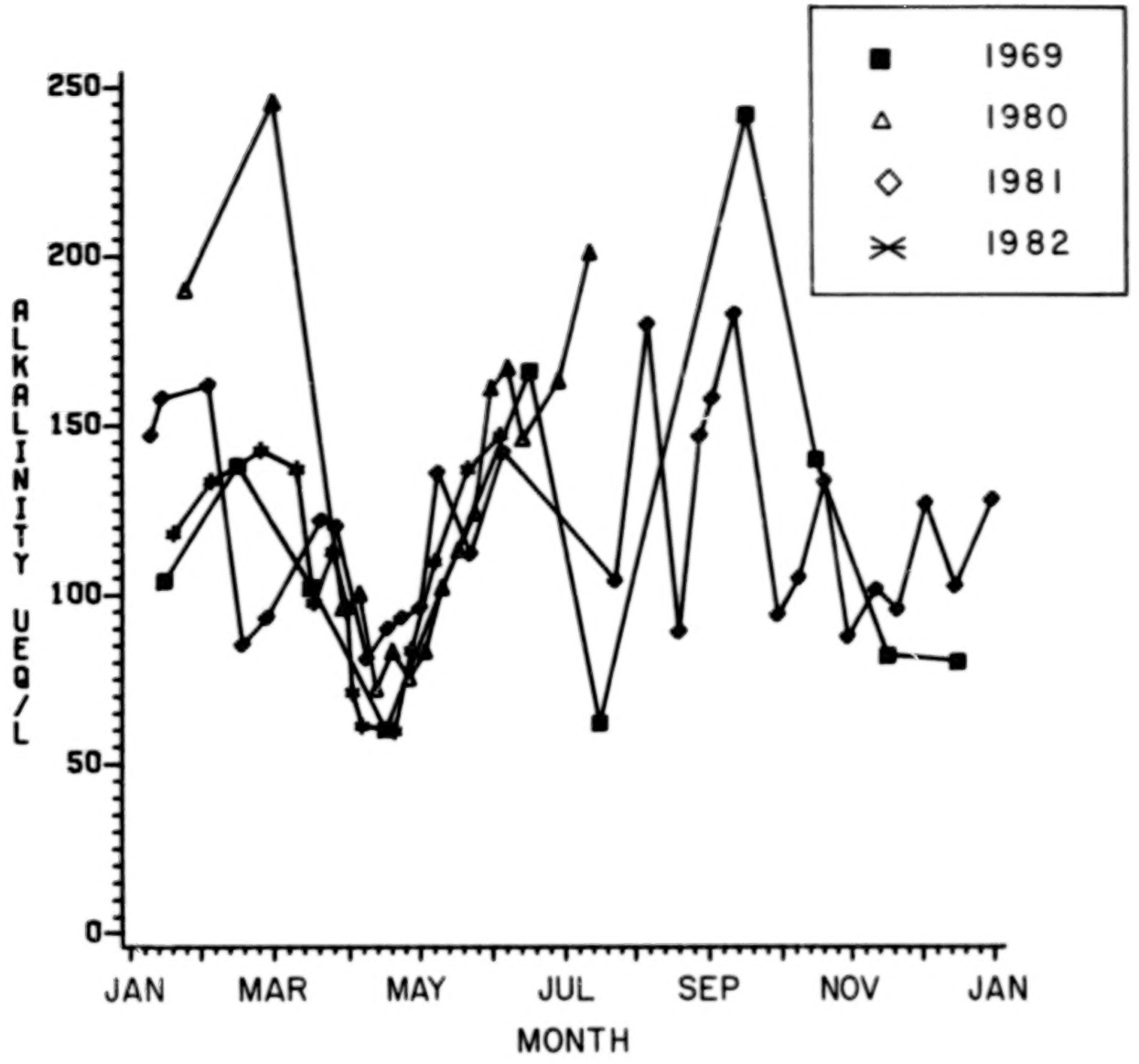

Figure 41. Comparison of recent and previous alkalinity for the Narraguagus River.

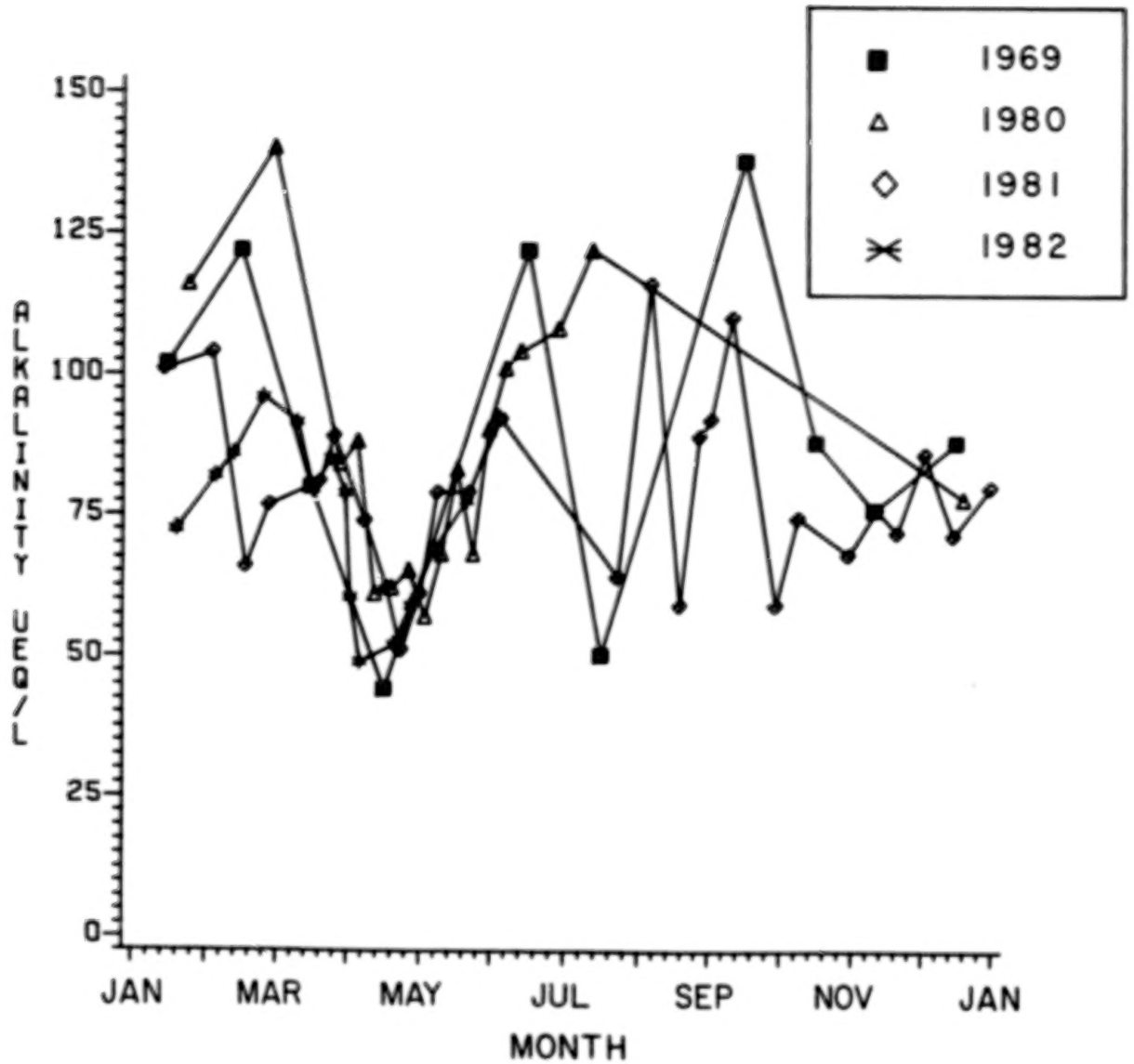

Figure 42. Comparison of recent and previous alkalinity for the Machias River.

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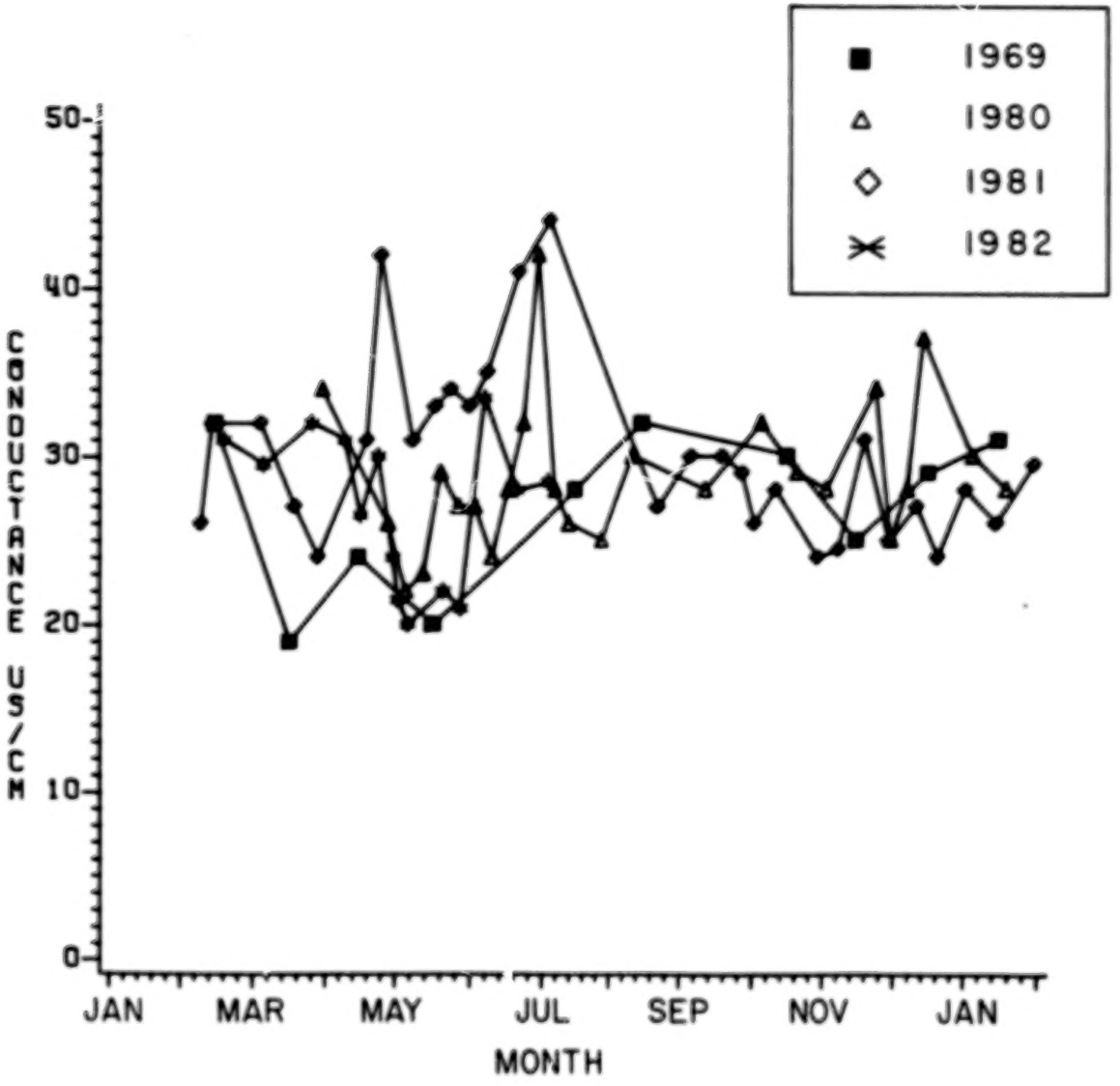

Figure 43. Comparison of recent and previous specific conductance for the Narraguagus River.

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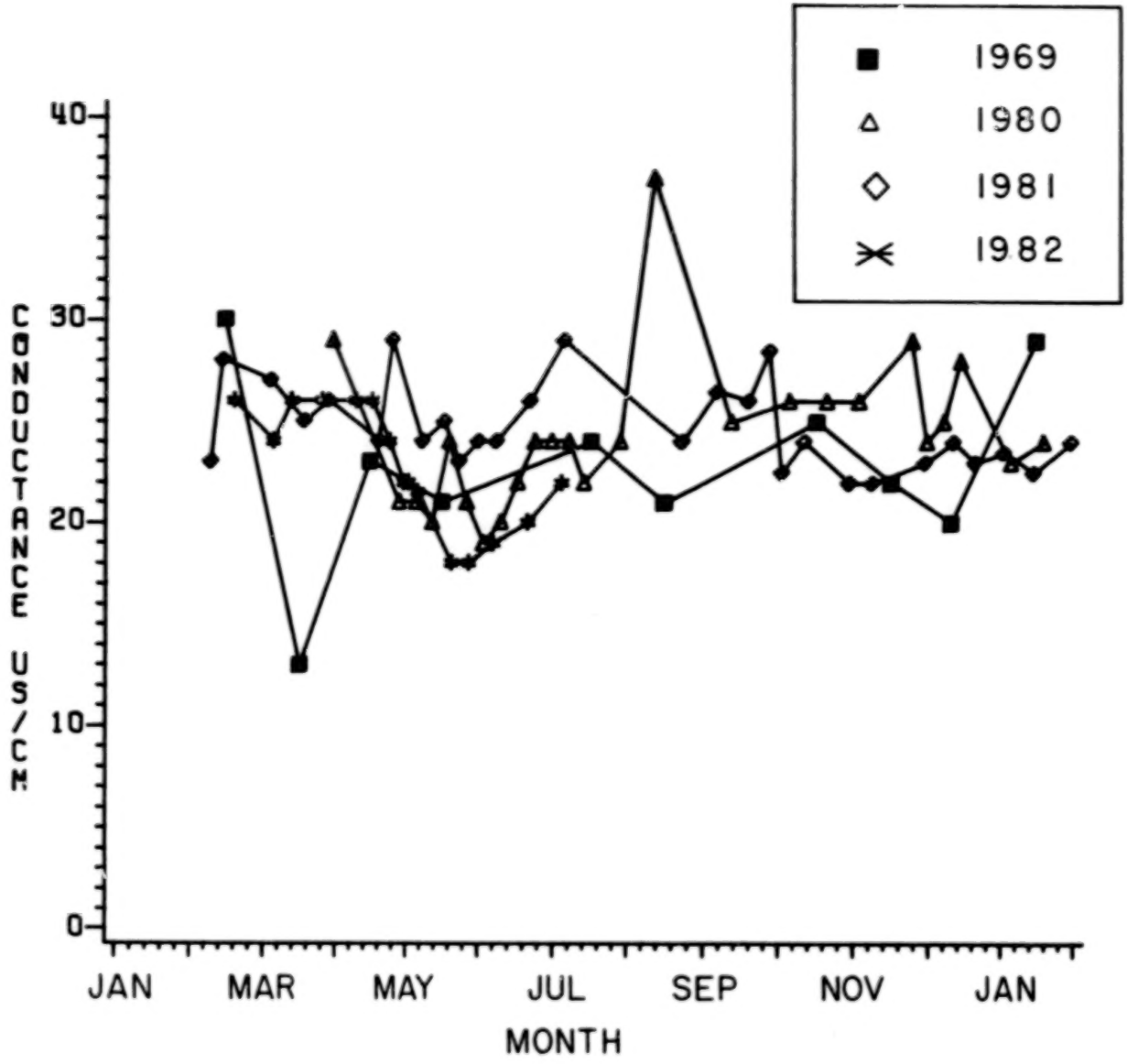

Figure 44. Comparison of recent and previous specific conductance for the Machias River.

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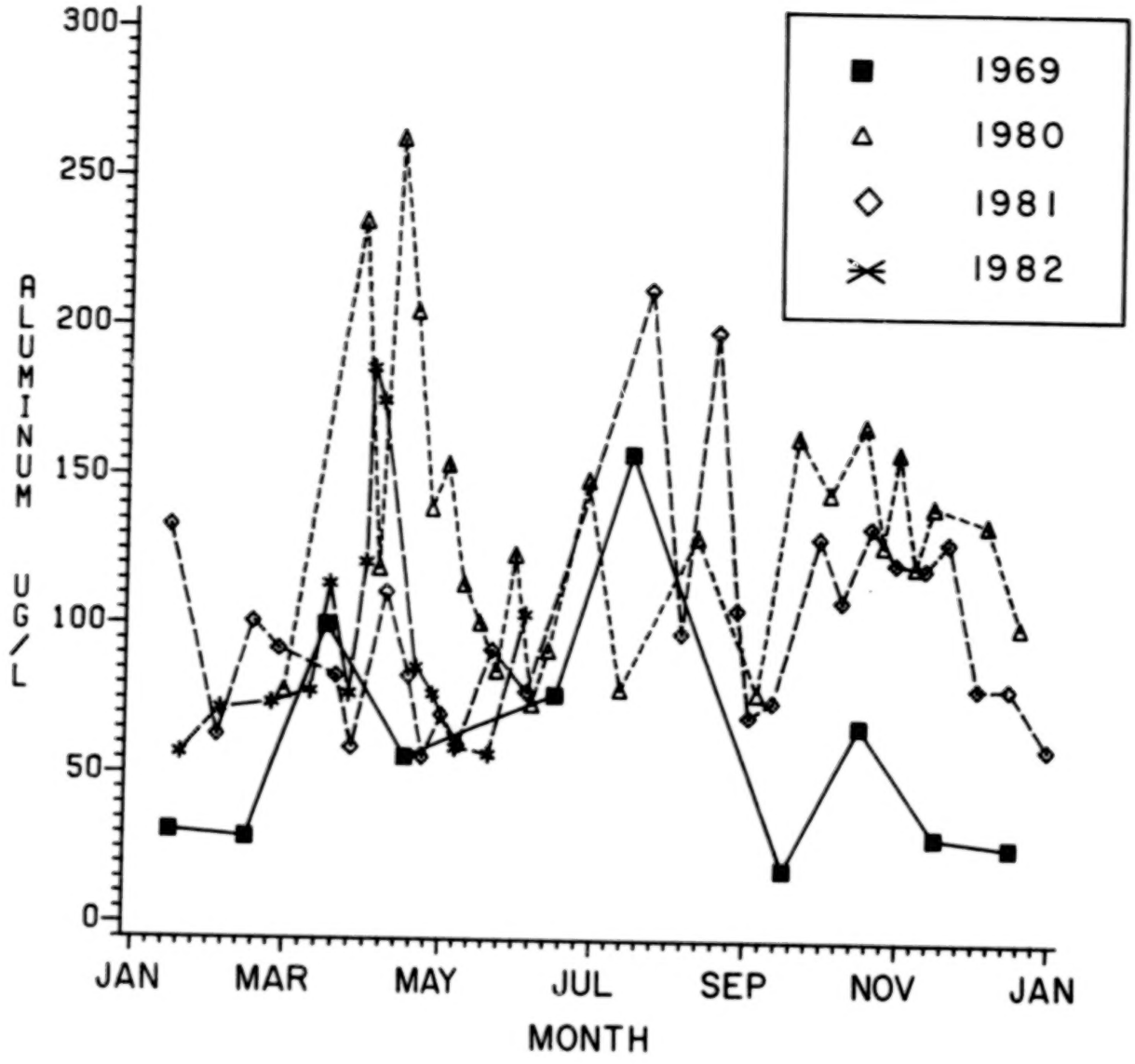

Figure 45. Comparison of recent and previous aluminum concentration for the Narraguagus River.

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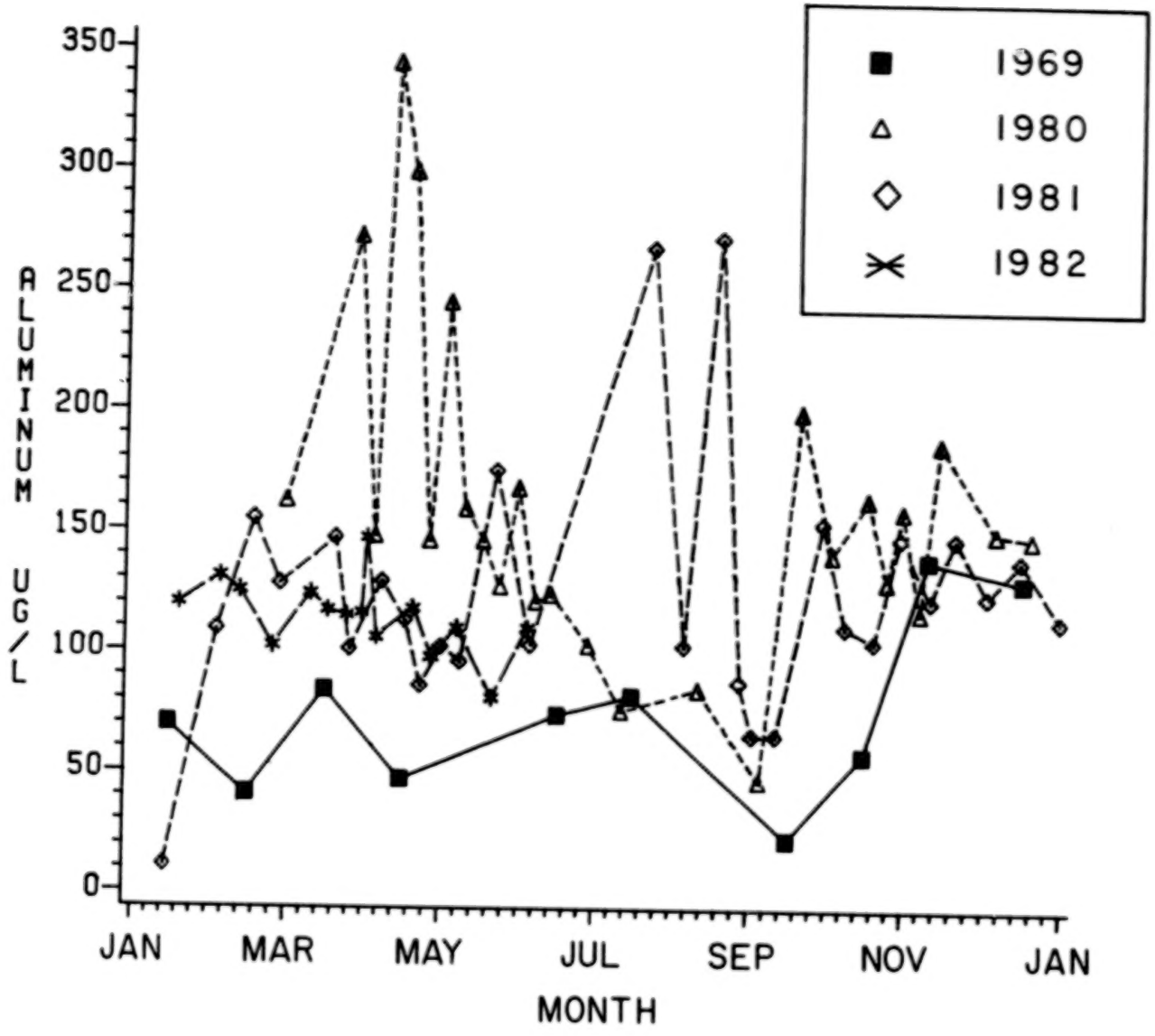

Figure 46. Comparison of recent and previous aluminum concentration for the Machias River.

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Discussion

Quality Assurance

Precision was high and bias was generally low for major ions, but were variable and less satisfactory for aluminum and manganese. We believe that the results are generally acceptable, however. The regressions of measured on calculated specific conductance and sum of cations on sum of anions indicate that there are no major measurement or coding errors in the data set.

Chemical Factors

pH, Alkalinity, and Conductance

The seasonal pattern of change in these three factors is apparently related to periods of high precipitation and increased discharge. The magnitude and timing of the declines that we observed were similar to those observed in other low order streams that are located in resistant bedrock and that receive precipitation of similar chemistry (Jeffries et al. 1979; Martin 1979; Christophersen and Wright 1980; Colquhoun et al. 1981; Webb 1982). These declines are associated with high precipitation and peak stream discharge, and follow snowmelt. However, Watt et al. (1983) found that the annual minimum pH and alkalinity occurred before the peak discharge in Nova Scotia rivers. They attributed this to the fact that snow was higher in pH than rain in this area so that snowmelt water did not depress stream pH or alkalinity. In the White River, pH and alkalinity are buffered by carbonate minerals in the watershed and show little relationship to precipitation or discharge.

The fall pH, alkalinity, and conductance declines are also associated with increased discharge that accompanies increased precipitation occurring as rain, before soils freeze and a snowpack forms. Similar declines have been observed in Norway (Webb 1982), Ontario (Jeffries et al. 1979), Nova Scotia (Watt et al. 1983), and New Hampshire (Martin 1979). Additional declines occurred in our streams during the summer of 1981, following intense precipitation events and again associated with increased discharge. The summer declines may be enhanced by the fact that precipitation is more acidic during summer than at other times of the year (National Atmospheric Deposition Program 1983). During periods of high precipitation water may enter streams via overland flow rather than percolation through soil.

In contrast to the above, Likens et al. (1977) reported that stream pH in the Hubbard Brook Experimental Forest was very stable seasonally, which was attributed to buffering by the terrestrial ecosystem. The stream pH was chronically depressed below 5.0.

There appeared to be a general relationship between bedrock geology class and soil sensitivity class in the watershed and stream pH, alkalinity, and conductance. Streams that were lowest in pH and alkalinity generally drained watersheds that had a high proportion of low sensitivity bedrock, soil, or both (e.g., Kerwin Brook, Narraguagus River), whereas streams that were highest in pH and alkalinity drained watersheds with a preponderance of non-sensitive materials (e.g., Harmon Brook, White River).

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All rivers in Maine were located in areas with moderately sensitive soils (McFee 1980), and all were lower in pH, alkalinity, and conductance than the White River, which was located entirely in a non-sensitive soil area. The lower pH, alkalinity, and conductance values in smaller, lower order streams may also result from the smaller watersheds of these streams, which provide less opportunity for precipitation water to percolate through soil. The degree to which influent water passed through inorganic soil horizons was found to be the critical factor governing lake pH and alkalinity in the Adirondack Mountain region of New York (Chen et al. 1983). Small streams also tend to have less diverse geology and soil types in their watersheds, offering less opportunity for buffering from incursions of higher buffering materials in the watershed. Johnson (1979) found that stream pH was highly correlated with order for small streams in the Hubbard Brook, New Hampshire, watershed. Low order streams had lower pH than higher order streams in the same watershed, even though ionic strength was the same. He attributed the neutralization of hydrogen ion to dissolution of preexisting aluminum hydroxide compounds in the upper soil horizons.

Other authors, however, believe that hydrogen ion from precipitation increases weathering reactions and is exchanged for base cations (Fisher et al. 1968; Martin 1979; Webb 1982). For example, Martin (1979) found that pH, alkalinity, and base cations increased from a headwater to a downstream site in a watershed in New Hampshire. In our streams aluminum concentration is highest in low order streams. As stream order increases aluminum concentration declines but conductivity and alkalinity increase. It appears that reduced pH increases aluminum solubilization initially. Later, the hydrogen ion is exchanged for base cations, pH increases, and aluminum is precipitated out of solution.

Color

Color is moderate to high in the Maine rivers, and virtually absent in the White River. Color was highest from late summer to early fall and may result from leaching of organic compounds from decaying vegetation at this time. Color was lowest during spring when discharge was highest and pH was lowest. Therefore the pH depression at high discharge cannot be attributed to increases in organic acids.

Aluminum

The increase in aluminum concentration at periods of high discharge probably results from increased aluminum dissolved from terrestrial rocks and soils and aquatic sediments by the increased hydrogen ion, especially considering that other cations decrease at this time. Many authors have shown that lake aluminum is highly correlated with pH (Wright and Gjessing 1976; Dickson 1980; Wright and Henriksen 1980; Schofield 1982; Haines and Alielaszek 1983), and this is consistent with the relationship between stream pH and aluminum hypothesized by Johnson (1979).

Inasmuch as we did not filter our samples or fractionate aluminum compounds, our data represent only total aluminum. Recent comparisons of filtered and unfiltered samples in our laboratory show little or no difference in aluminum concentration. We conclude that particulate aluminum is very low in these streams. Color is appreciable in the Maine

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streams, and much of the aluminum may have been present as an organic complex. Aluminum concentration was positively correlated with organic anion concentration in all nine streams.

Cations

The concentrations of cations in the first order streams in Maine were similar to those from comparable (similar order, bedrock and soil types, and precipitation chemistry) streams reported elsewhere (Table 9). The slightly higher sodium concentrations in our streams probably reflect the proximity to the ocean; concentrations were even higher at Birkenes. Higher order Maine streams had higher calcium concentrations, but other cations were little, if any, higher than in first order streams. The White River had much higher cation concentrations than third order Maine rivers, reflecting the presence of more soluble bedrock and higher concentrations of exchangable soil cations in this area. Calcium was the dominant cation in all streams, as it generally is in surface waters world-wide (Livingstone 1963).

The seasonal cycles of cation concentrations in our streams are similar to those reported for New Hampshire streams (Likens et al. 1977; Martin 1979). The spring and fall declines in cations result from dilution of base flow by precipitation runoff and snowmelt. However, in Sweden (Calles 1983) and Norway (Webb 1982), base cations, primarily calcium, increase at spring snowmelt and high discharge, and decline in summer. This is attributed to leaching of base cations by hydrogen ion. In our streams hydrogen ion and aluminum increase at spring snowmelt and high discharge. Increases in base cations occur at downstream locations in higher order streams concomitant with decreases in hydrogen ion and aluminum.

Anions

The most abundant anion in the low order streams was sulfate, and in the higher order streams bicarbonate. Bicarbonate is the most abundant anion in surface waters world-wide (Livingstone 1963). In acidified surface waters sulfate replaces bicarbonate (Wright and Henriksen 1983). Sulfate concentrations were not highly related to stream order in the Maine streams, being only slightly lower in higher order streams (Table 9), but sulfate was considerably higher in the White River than any Maine river, even though the White River is not acidified. This may simply be a reflection of the much higher concentration of all ions in this river, inasmuch as bicarbonate far exceeds sulfate. Bicarbonate was higher in third order than in first or second order streams in similar geological and soil regions in Maine, possibly as a result of weathering reactions.

Nitrate was generally present at very low concentrations in the Maine rivers. This is expected because of the high biological uptake rates for this important nutrient. The intermediate nitrate concentration in Sinclair Brook is unexplained. Nitrate was consistently elevated in all samples and good ionic balance is achieved, ruling out analytical error. Nitrate was relatively high in the White River, probably as a result of agricultural and urban runoff in this more developed river basin. Nitrate concentrations in the Maine streams were comparable to Sweden (Calles 1983)

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Table 9. Mean concentrations of major ions in streams located in areas where bedrock is resistant to weathering and precipitation is acidic (pH <4.5). Concentrations are in μeq/l.

Location	Ion										
	Ca	Mg	Na	K	H	Al	SO_4	NO_3	Cl	HCO_3	Organic Anions
Maine, first order[a]	66	37	72	10	3.0	18	59	3	48	33	48
Maine, third order[a]	107	37	76	12	0.6	13	54	5	51	98	44
New Hampshire[b]	100	25	44	15	1.6		94	37		28	
New Hampshire[c]	120	29	57	15	0.4		82	40		73	
New Hampshire[d]	83	31	38	6	12.6		130	31	15	27	
Sweden[e]	100-400		40-90				60-200	<1-3			
Norway[f]	50	15	50-80	7			80-90	10-15	50-80		
Norway[g]	67	40	123	7	33	71	152	7	123	<1	

[a]This study. [b]The Bowl, headwater location (Martin 1979). [c]The Bowl, downstream location (Martin 1979). [d]Hubbard Brook (Likens et al. 1977). [e]Range for three watersheds (Calles 1983). [f]Tovdal River (Webb 1979). [g]Birkenes (Christophersen and Wright 1980).

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and Norway (Webb 1982), but much lower than in New Hampshire. Likens et al. (1977) report nitrate concentrations averaging about 30 μeq/l in the Hubbard Brook system, and Martin (1979) found that nitrate concentrations averaged 37-40 μeq/l in The Bowl natural area. Both these areas have deciduous forest vegetation, whereas forests are primarily coniferous in our study area.

The seasonal pattern of bicarbonate concentration is similar to that of cations in all streams, for the same reason. Sulfate concentrations were highest at the time of high discharge, when pH was lowest. Nitrate concentrations were relatively constant, but there generally was a small increase coinciding with snowmelt and preceeding peak discharge. This may result because snow is relatively high in nitrate, and biological activity is relatively low at this time. Galloway and Dillon (1983) found that nitrate increased in lakes and streams following snowmelt, and Gallway et al. (1983) observed that sulfate was relatively constant but nitrate increased during spring snowmelt in three watersheds in New York. These results coincide with our findings. Both sulfate and nitrate tended to be lowest during summer base flow, when biological activity was highest, and gradually increased during fall and winter, when biological activity declined. Calles (1983) found that sulfate increased at peak runoff in one stream in Sweden, nitrate increased in a second stream, and neither increased in a third stream. The pH of these streams was not reported. Webb (1982) reported a general increase in sulfate and decrease in nitrate during the peak discharge period for the Tovdal River, Norway. At this time, river pH declined from 5.0 to 4.6.

Ion Correlations

In our streams, pH was most highly correlated to discharge and to alkalinity. There were significant correlations for all streams tested. There were significant correlations with organic anions in three streams (negative), with nitrate in one stream (negative), and with sulfate in one stream (positive). The positive correlation with sulfate is probably spurious. Thus the pH decline at peak discharge probably results from dilution of base flow with low alkalinity runoff water, rather than from an increase in sulfate or nitrate.

Ion Discharge

Ion discharge from a watershed is a function of the chemistry of precipitation and the interaction of the chemicals in precipitation with those in the terrestrial components of the watershed. Among the interactions that may take place are the following:

uptake and release by vegetation
cation exchange reactions
weathering reactions
oxidation/reduction reactions, including those mediated by microbes
accumulation and depletion from watershed reservoirs
formation and dissociation of carbonic acid
dissolution of organic and other weak acids

Along with the above interactions, the chemical nature of the rocks, soil,

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and till in the watershed, the type of vegetation, and hydrological characteristics that affect contact time between precipitation and watershed components will ultimately control the chemistry of water discharged from a watershed.

All watersheds located in glaciated areas for which ion discharge data were available had a net loss of all cations except hydrogen (Table 10). Net loss was generally highest for calcium, intermediate for magnesium and sodium, and lowest for potassium. The White River had the highest net output of cations, probably as the result of carbonate weathering reactions (Johnson 1979). Wright and Johannessen (1980) reported that cation output far exceeded acid input in non-granitic watersheds, probably because of carbonation reactions. The net output of cations was lowest in the Rawson Lake watershed, which is granitic and does not receive acidic precipitation (Schindler et al. 1976). Although Johnson et al. (1972) believed that the cation discharge from Hubbard Brook was low as compared to regional or world-wide averages, the net loss of cations for this watershed is higher than that for acidified areas in Scandinavia.

The net output of cations was higher in higher order streams. Martin (1979) found higher cation discharge at downstream as compared to upstream locations. Both the Narraguagus and White rivers are third order streams and cation concentrations are relatively high as compared to the other streams in Table 10, most of which are first order streams. Johnson (1979) found that ionic strength increased with stream order as strong acids were neutralized, allowing carbonic acid to ionize and carbonation reactions to occur. There was also an exchange of aluminum compounds for base cations in higher order streams. Galloway et al. (1983) found that depth of soil and till were also important factors in determining discharge of base cations from watersheds in New York. Generally higher order streams will have larger watersheds, lower gradients, and thicker soils, all of which contribute to increased contact of precipitation with soil particles, which in turn promotes weathering reactions. An examination of Table 10 strongly suggests that some factor or factors other than acid deposition alone are responsible for the differences in cation discharge among the watersheds listed. Rather minor differences in the chemistry of bedrock or soils, in addition to differences in soil contact time, could appreciably affect the chemistry of the precipitation as it passes through the system.

Some authors have attempted to quantitatively relate the deposition of acid to the discharge of cations. Fisher et al. (1968) assumed that H ion input approximated cation output. Their data supported this assumption, but they did not consider precipitation inputs of other cations. Dillon et al. (1980) estimated the input of acid as the net retention of H ion and NH_4 ion in the watershed plus the loss of HCO_3 ion from the watershed, and output of ions mobilized by acid as the sum of cations lost plus NO_3 retained. In practice, NH_4 and NO_3 ion are roughly equivalent, canceling each other, and may be ignored. Wright and Henriksen (1983) calculated two functions -- $g(Ca^* + Mg^*)$ and SA -- and related these functions to SO_4 resulting from atmospheric deposition. The function $g(Ca^* + Mg^*)$ is empirically derived and is $0.93 (Ca^* + Mg^*) -14$, where the asterisk signifies correction for marine aerosols. This is an estimate of major cations in the absence of acid deposition. The function SA is defined as $H + Al - HCO_3$ and represents strong acid. Net SO_4 is computed by

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Table 10. Precipitation input, discharge output, and net retention (input - output) of ions for a number of watersheds located in glaciated areas in North America and Europe. Units are meq/m^2/year.

	Ion																														
	Ca			Mg			Na			K			H			Al			HCO_3			SO_4			NO_3			Cl		
	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net	in	out	net
Maine[a]	11	130	-119	16	46	-22	92	88	4	3	18	-15	50	0.95	49	0	20	-20	0	87	-87	66	81	-15	23	10	13	108	61	47
Vermont[a]	8	182	-174	5	67	-62	5	86	-81	0	8	-8	51	0.12	34	0	7	-7	0	162	-162	50	106	-56	32	35	-3	6	99	-93
Norway[b]	7	35	-28	3	12	-9	10	16	-6	3	3	0	59	16	43	0	16	-16	0	0	0	63	50	13	25	1	24	11	11	0
Norway[c]	21	72	-51	29	43	-14	123	133	-10	8	8	0	127	36	91	0	77	-77	0	0	0	164	164	0	84	8	76	133	133	0
Sweden[d]	19	66	-47	6	30	-24	12	23	-11	3	4	-1										49	29	20	3	0.3	3	7	7	0
New Hampshire[e]	16	115	-99	6	28	-22	6	44	-38	6	15	-9							0	29	-29	112	101	11	43	47	-4			
New Hampshire[f]	16	132	-116	6	31	-25	6	57	-51	6	18	-12							0	69	-69	112	90	22	43	47	-4			
New Hampshire[g]	11	68	-57	5	26	-21	7	32	-25	2	5	-3	97	10	87	08	-38	-0	13	-13	80	112	-32	32	28	4	20	14	6	
Ontario[h]			-55			-34			-7			-3	70	3	67						-32						32		
Ontario[i]	14	22	-8	7	15	-8	4	12	-8	2	3	-1	8	3	5							6	7	-1	51	6	45	6	1	5

[a]This study. [b] Langtjern watershed (Wright 1983). [c]Birkenes, South Norway (Wright and Johannessen 1980). [d]Central Sweden, average for three watersheds (Calles 1983). [e]The Bowl, headwater site (Martin 1979). [f]The Bowl, downstream site (Martin 1979). [g]Hubbard Brook (Likens et al. 1977). [h]Muskoka-Haliburton area, Harp Lake (Dillon et al., 1980). [i]Rawson Lk., Ontario, average for three streams (Schindler et al. 1976).

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subtracting estimated natural, or "background," SO_4^* from measured SO_4^*. Then: $9(Ca^* + Mg^*) + SA$ = net SO_4^*.

Comparison of these various methods for watersheds that have data available (Table 11) indicates that the discharge of cations far exceeds H ion deposition for all watersheds except Langtjern, Norway. The question arising, then, is how are cations mobilized from a watershed if not by H ion in precipitation. The apparent explanation is that there is considerable internal H ion generation from ionization of carbonic acid, which could be appreciable where mineral acid inputs are neutralized by ion exchange reactions in the watershed (Johnson 1979; Wright and Johannessen 1980). Although wet deposition measurements probably underestimate H ion deposition by a factor of one third, even making this correction does not account for the discrepancy in our data.

The net retention of H ion plus HCO_3 lost generally provides a better approximation of the sum of cations lost from the watersheds. This relationship presumes that the output of HCO_3 results from acid neutralization reactions in the watershed, including internally generated acids. The neutralization process plus other weathering reactions that consume H ion results in the release of cations, including both aluminum and base cations.

The function $g(Ca^* + Mg^*) + SA$ of Wright and Henriksen (1983) represents H ion that passes through the system unneutralized plus that which is neutralized and results in the release of Al and HCO_3. Internally generated H ion is assumed to be responsible for the estimated normal (or "background") sum of major cations in watershed discharge, as well as part of the HCO_3 ion. These two quantities should approximate SO_4 correction for normal ("background") SO_4 and that resulting from marine aerosols. The agreement is fair. In a previous study we found that this relationship also generally held true for lakes in New England (Haines and Akielaszek 1983). The strength of this relationship is that it allows calculation of surface water pH if acid deposition should change (Wright and Henriksen 1983). Watt et al. (1983) compared recent and historical water chemistry for rivers in Nova Scotia. They concluded that increased acid deposition had resulted in increased sulfate, aluminum, and H ion and decreased HCO_3 in these rivers.

Thompson (1982) proposed that the sum of non-marine base cations -- CDR -- would reflect leaching of cations by acid deposition. Among watersheds for which such data were located (Table 12) there seems to be little relationship between acid deposition and CDR. The chemistry of bedrock and soil, watershed characteristics such as size, depth of soil and till, etc., and the deposition of cations are more likely explanations of differences in CDR.

It is nearly universal that watersheds have a net loss of bicarbonate, providing only that the pH of the drainage water is sufficiently high for bicarbonate ion to exist (Table 10). There is essentially no bicarbonate ion in precipitation. The source of bicarbonate in these noncalcareous systems is apparently dissociation of carbonic acid. The largest bicarbonate loss was from the White River, which was the largest river and

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Table 11. Comparison of various parameters assumed to reflect acid deposition or cation discharge. All units are meq/m^2/year.

Location	cations lost	H ion input	H ion retained + HCO_3^- lost	$g(Ca^* + Mg^*)$ + SA	net SO_4^*
Maine[b]	21	50	136	71	25
Vermont[b]	339	51	213	40	46
Norway[c]	59	59	43	60	34
Norway[d]	152	127	91	176	136
New Hampshire[e]	144	97	100	105	61
Ontario[f]	99	70	99	-	-
Ontario[g]	25[a]	8	-	-	-

[a]Not including Al. [b]This study. [c]Langtjern (Wright 1983). [d]Berkenes (Wright and Johannessen 1980). [e]Hubbard Brook (Likens et al. 1977). [f]Harp Lake (Dillon et al. 1980). [g]Rawson Lake (Schindler et al. 1976).

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Table 12. Cation Denudation Rate, and H ion deposition, meq/m^2/year, for various watersheds.

Location	CDR	H ion
Narraguagus R.[c]	215	50[a]
White R.[c]	343	51[a]
New Hampshire (The Bowl, headwater)[d]	202	158
New Hampshire (The Bowl, downstream)[d]	238	158
New Hampshire (Hubbard Brook)[e]	115	97
North Carolina (hardwoods)[f]	116	-[b]
New England (upper drainage basins)[g]	220	-[b]
Northeastern U.S.[g]	680	-[b]
Oregon (S. Cascade Glacier)[h]	930	-[b]
Ontario (mean of 3 streams)[i]	51	10
Newfoundland (mean of 10 streams)[j]	124	20
Nova Scotia (mean of 11 streams)[j]	106	40
Norway (Langtjern)[l]	53	59
Norway (Birkenes)[m]	125	127
Sweden (mean of 3 streams)[n]	116	-[b]
Great Britain[o]	78	10
World average[h]	390	-[b]

[a]Wet deposition only. [b]Not measured. [c]This study. [d]Martin (1979). [e]Likens et al. (1977). [f]Johnson and Swank (1973). [g]Johnson et al. (1972). [h]Reynolds and Johnson (1972). [i]Schindler et al. (1976). [j]Thompson (1982). [k]Thompson et al. (1980). [l]Wright (1983). [m]Wright and Johannessen (1980). [n]Calles (1983). [o]Cryer (1976).

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had the highest alkalinity concentration. This river also probably has carbonate minerals in the watershed. Johnson et al. (1972) found that alkalinity increased as stream size increased, and Galloway et al. (1983) found that the largest loss of bicarbonate was from the watershed where alkalinity was highest.

Nitrate is generally strongly retained by watersheds. The only exception noted in the literature was one stream in New Hampshire (Martin 1979). This loss was small and may represent a net balance in a mature, undisturbed watershed. In our data the White River had a large net loss of nitrate, possibly as the result of agricultural and urban runoff. Mechanisms of nitrate retention include uptake by vegetation, accumulation in soil organic matter, loss of volatile nitrogen compounds such as nitric oxide, or dissimilatory reduction such as denitrification or ammonification (Calles 1983; Galloway and Dillon 1983).

Sulfate discharge was quite variable among rivers ranging from net loss to balance to net retention. A net loss of sulfate may indicate a source of sulfate in the watershed other than precipitation (Galloway et al. 1983), or an underestimation of sulfate input because of failure to account for dry deposition or gaseous sulfur dioxide (Dillon et al. 1982). The data from Sweden (Calles 1983), New Hampshire (Martin 1979), and Ontario (Schindler et al. 1976) are bulk deposition, which underestimates sulfate deposition. Both the Narraguagus and White rivers had net losses of sulfate, even though deposition estimates were adjusted to include dry deposition. A net retention of sulfate could result from accumulation of sulfur in soil organic matter, release of volatile sulfur compounds such as methyl sulfide, or sulfate reduction to form sulfide minerals (Calles 1983; Wright 1983). A balance of sulfate input and output does not necessarily mean that sulfate does not enter into any significant reaction pathways. In fact, sulfate may function as a "mobile anion" (Christophersen et al. 1982) resulting in net loss of base cations.

Chloride is generally conserved and is geochemically unimportant. It should therefore be in balance for input and discharge. In some cases this is assumed, and any discrepancy is assumed to result from measurement errors and ion deposition is adjusted to result in balance (Calles 1983; Wright 1983). Streams in New Hampshire (Likens et al. 1977) and Ontario (Schindler et al. 1976) have a net retention of chloride. In our data the Narraguagus had a net retention and the White had a net loss. Road deicing salt may contribute to the net loss for the White River. Chloride deposition measurements are much higher for the Narraguagus River because of the proximity to the ocean. The precipitation station was much closer to the ocean than was the water chemistry station.

Intragravel Water

Intragravel water was similar to, but slightly more alkaline than, stream water. Inasmuch as both stream and intragravel water exhibited similar temporal chemistry patterns, the exchange between the two types must be relatively rapid. The slightly higher pH, alkalinity, calcium, and specific conductance in intragravel water may result from very fine particles of substrate that exert a minor neutralizing effect. In New Brunswick and Nova Scotia streams intragravel pH was slightly higher than

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stream water for streams with pH <5.5, but slightly lower for streams with pH >5.5 (G. Lacroix, Fisheries and Oceans, St. Andrews, New Brunswick, personal communication). Williams and Hynes (1974) found that pH declined from 7.8-8.2 at the water-substrate interface to 7.4-7.6 at 20 cm depth in the substrate in the Speed River, Ontario. Water chemistry within gravel-filled hatching boxes placed in two lakes was measured by Gunn and Keller (1980). They found slightly higher pH, alkalinity, calcium, and specific conductance in intragravel water from mixed noncalcareous gravel placed in acidic (pH 5.2) Lake George. However, there was no difference between ambient lake and intragravel water from a circumneutral lake (pH 6.7).

Intragravel water from our streams was extremely high in aluminum. These high concentrations may have resulted from clay particles washed from the sediment. However, aluminum was highest in the intragravel water with the lowest pH, and intragravel aluminum concentrations followed temporal patterns similar to stream water aluminum. If this difference is real, elevated aluminum could constitute a threat to salmonid reproduction in these streams. Because of the small number of samples and the lack of filtering, these results should be interpreted cautiously.

Comparisons with Previous Data

Except for aluminum, there was little or no difference between water chemistry factors measured in 1969 and those in our study. This is not too surprising considering the time interval between measurements was only 12 years. Precipitation chemistry has probably changed little during this time. We expected that continued acid deposition would increase leaching of base cations or decrease alkalinity, but neither seems to have occurred. In contrast to this, Thompson et al. (1980) found a significant decline in pH and calcium in three Nova Scotia rivers between 1954-55 and 1973, and substantial pH declines from 1965 to 1973, but no such declines in three Newfoundland rivers. The Nova Scotia rivers had mean annual pHs ranging from 4.4 to 6.2, and CDRs of 80 to 115 meq/m^2/year. The pHs were 4.8 to 6.0 and CDRs were 150-200 meq/m^2/year for the Newfoundland rivers. However, Watt et al. (1983) found no change in calcium, magnesium, sodium, or potassium between 1954-55 and 1980-81 in four Nova Scotia rivers. They did find a significant decrease in bicarbonate and increase in hydrogen ion, aluminum, and sulfate. We previously found that lakes in Maine located near the rivers studied here had declined in pH and alkalinity (Haines and Akielaszek 1983).

We did find an increase in aluminum concentration as compared to the historical values, even though hydrogen ion concentration of the rivers was not different. It is possible that the increase represents an improvement in methodology. Aluminum is an analytically difficult element, and quantification methods have improved greatly in recent years.

Historical comparisons in streams are subject to error because of differences in discharge, vegetation, and climatic conditions. These factors also affect lakes, but to a lesser extent than in streams. We were fortunate to have relatively similar discharge levels in our data sets, and to locate historical data that were collected over an annual cycle. A much

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longer series of data would be required to accurately assess historical chemical changes in these rivers.

Potential Effects on Atlantic Salmon

Reduction or elimination of native Atlantic salmon populations has been reported for acidic rivers in southern Norway and Nova Scotia. In Norway, Atlantic salmon have disappeared from seven rivers with a mean pH of 5.12 (Leivestad et al. 1976). Mortality of naturally produced presmolts has been observed in rivers at pH 5.15-5.50 and labile aluminum concentrations of 30-55 µg/l (Hesthagen and Skogheim 1983). Labile aluminum usually constitutes 60 to 98% of total aluminum in Norwegian rivers (Skogheim et al. 1983). In Nova Scotia, Atlantic salmon populations have been severely reduced or eliminated from 10 rivers with annual mean pH 5.0 or less (Watt et al. 1983). Rivers with mean pH above 5.0 had no declines in fish populations.

The difference in the pH at which Atlantic salmon are affected in Norwegian versus Nova Scotian rivers is most likely the result of different amounts of color (= dissolved organic matter) in the rivers of these two regions. The increased dissolved organic matter chelates proportionally more of the aluminum, rendering it non-toxic to fish (Driscoll et al. 1980). Color is very low in the Norwegian rivers (<5 color units; Hesthagen and Skogheim 1983), and ranges from 30 to >100 color units in Nova Scotia rivers (Watt et al. 1983).

The pH and aluminum concentrations in some of the first and second order streams in Maine (Table 6) are similar to those of Norwegian rivers where Atlantic salmon mortalities have recently been reported. However, inasmuch as the color levels of the Maine rivers are similar to those of Nova Scotia rivers, such severe mortalities may not occur in the Maine rivers at the present pH and aluminum conditions. Only total aluminum was measured in Nova Scotia and Maine rivers, but it is probable that only half the aluminum or less is present in the labile, toxic form. The conditions of the most acidic Maine rivers appear to be marginally toxic to sensitive life stages of Atlantic salmon. Although marked population declines may not yet occur, low levels of mortality may result and prevent the full utilization of available spawning and nursery habitat.

Surveys indicate that tributaries contribute about 34% of the total spawning habitat in the Machias River, about 19% in the Narraguagus River, and about 30-40% in the East Machias River (Bryant 1952; E. Baum and K. Beland, Atlantic Sea Run Salmon Commission, personal communication). Therefore tributaries constitute a significant portion of available Atlantic salmon habitat in Maine.

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Conclusions

A survey of water chemistry was conducted in nine Atlantic salmon rivers in New England. Eight streams were located in Maine, ranged in size from first to third order, and all contained native populations of Atlantic salmon. One river was located in Vermont, was third order, and was being stocked with Atlantic salmon. All streams exhibited a seasonal pattern of change in chemical composition. At periods of high discharge, which were associated with spring snowmelt and increased precipitation in spring and fall, pH declined (hydrogen ion increased), base cations and alkalinity decreased, and aluminum increased. Sulfate tended to increase with discharge, especially during the spring high discharge period, and nitrate generally reached a peak slightly before peak discharge. The magnitude of the seasonal change was largest in first order streams in Maine, and smallest in the third order stream in Vermont. The low pH and high aluminum concentrations reached are not as severe as those in Norway and Nova Scotia, where Atlantic salmon populations have declined as a result of acidification.

The chemistry of these streams reflects the interaction of precipitation chemistry, watershed hydrology, and chemistry of soils, till and bedrock in the watersheds. First order streams with small watersheds composed of geologic materials resistant to weathering reacted the most to atmospheric inputs of acid, but the effects of acidification, are not yet severe. Atmospheric deposition of acid was not sufficient to account for all ions leached from these watersheds. The output of base cations and aluminum, balanced by bicarbonate and sulfate, far exceeds the amount of hydrogen ion deposited. The excess is most likely produced by internal generation of hydrogen ion from dissociation of carbonic acid.

The present chemical conditions in the rivers surveyed are not yet critical for Atlantic salmon survival. However, continued or increased deposition of acid may further degrade conditions in the small tributary streams, which constitute 20-40% of the available Atlantic salmon habitat in these rivers.

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Appendix A

Water chemistry data collected from nine rivers in Maine and Vermont.

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Appendix A.

NARRAGUAGUS RIVER

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
12480	6.45	.	156	.	190	.	.	.	.	.	.	.	.	.
22780	6.55	6.55	216	216	245	246	34	.	30	.	181	84	14	51
32880	6.15	.	71	.	96	.	26	.	40	.	102	82	15	35
40480	6.45	.	76	.	100	.	22	.	40	.	96	70	14	33
41180	6.05	.	41	.	72	.	23	.	50	.	82	81	18	32
41880	6.25	.	51	.	83	.	29	.	60	.	96	90	17	34
42580	6.15	.	51	.	75	.	27	.	50	.	98	96	16	35
50280	6.30	.	63	.	83	.	27	.	70	.	102	119	15	35
50980	6.50	.	78	.	102	.	24	.	60	.	106	81	15	36
51680	6.50	.	88	.	113	.	28	.	60	.	115	102	14	37
52380	6.70	.	104	.	124	.	32	.	50	.	121	108	15	38
53080	6.75	.	135	.	161	.	42	.	60	.	138	152	17	41
60680	7.00	.	128	.	167	.	28	.	50	.	129	74	14	39
61280	7.10	.	117	.	146	.	26	.	70	.	121	73	13	37
62780	7.05	.	136	.	163	.	25	.	50	.	137	81	15	41
71180	7.20	.	172	.	201	.	30	.	50	.	145	78	14	43
81180	7.10	.	152	.	.	.	28	.	100	.	144	88	16	44
90480	7.05	.	172	.	.	.	32	.	70	.	153	90	16	46
91980	6.85	.	118	.	.	.	29	.	110	.	153	87	15	49
100280	6.50	.	100	.	.	.	28	.	130	.	146	81	12	47
101680	6.35	.	76	.	.	.	.	.	.	.	132	80	15	45
102480	6.70	.	123	.	.	.	34	.	100	.	126	80	14	43
103080	6.45	.	71	.	.	.	25	.	110	.	121	74	15	43
110680	6.55	.	89	.	.	.	28	.	70	.	119	78	13	40
111380	6.50	.	79	.	.	.	37	.	60	.	119	97	14	42
120480	5.95	.	35	.	.	.	30	.	80	.	98	102	12	38
121880	6.30	.	101	.	.	.	28	.	50	.	124	89	13	42
10981	6.15	.	120	.	147	.	26	.	60	.	.	.	.	.
11481	6.30	.	132	.	158	.	32	.	50	.	140	74	15	41
20381	6.40	.	136	.	162	.	32	.	40	.	140	70	13	41
21781	6.00	.	59	.	85	.	27	.	50	.	100	61	13	33
22681	6.35	.	66	.	93	.	24	.	50	.	95	57	13	33
31981	6.55	.	97	.	122	.	31	.	40	.	115	65	13	33
32581	6.65	.	94	.	120	.	42	.	30	.	120	91	15	33
40781	5.95	.	52	.	81	.	31	.	50	.	90	83	18	33
41681	6.20	.	63	.	90	.	33	.	40	.	105	83	15	33
42281	6.25	.	71	.	93	.	34	.	30	.	120	122	13	41
43081	6.05	.	78	.	96	.	33	.	40	.	120	100	10	41
50781	6.75	.	113	.	136	.	35	.	60	.	135	126	13	41
52181	6.15	.	81	.	112	.	41	.	70	.	120	122	10	41
60481	6.85	.	109	.	142	.	44	.	80	.	135	139	15	41
72281	6.20	.	78	.	104	.	27	.	140	.	145	78	13	49
80581	6.85	6.80	144	155	172	188	30	30	90	100	160	91	13	49
81881	5.75	5.70	42	49	89	89	30	30	130	150	145	65	15	49
82781	6.75	6.85	112	111	145	149	29	29	.	.	140	78	13	41
90181	6.85	.	128	.	158	.	26	26	.	.	140	83	13	41
91081	6.75	6.80	143	148	183	183	28	28	.	80	135	83	13	41
92881	6.30	.	65	.	94	.	24	.	120	.	115	70	13	33
100781	6.30	6.40	72	74	104	106	25	24	90	100	105	70	10	33
101981	6.45	6.55	89	109	120	147	31	.	80	.	95	87	13	33
102981	6.05	6.12	52	54	81	94	24	26	100	100	95	70	15	33
111081	6.30	6.36	73	80	95	108	27	27	90	90	90	70	13	33
111981	6.35	6.35	65	71	89	102	24	24	80	80	85	70	13	33

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Appendix A. Continued.

120181	6.55	6.59	98	100	122	132	28	28	60	60	120	74	10	41
121481	6.40	6.40	74	76	99	106	26	26	60	60	110	65	10	33
123081	6.65	6.55	99	103	126	130	29	30	40	40	120	70	10	33
11982	6.10	6.22	88	84	119	117	31	31	60	60	115	71	11	35
20482	6.10	6.18	102	106	130	137	30	29	50	50	120	67	11	37
22382	6.30	6.29	110	116	139	146	32	32	60	60	130	77	13	38
30982	6.25	6.33	107	106	137	137	31	31	50	50	135	69	13	41
31682	6.05	6.10	69	70	95	100	27	26	50	50	115	64	13	38
32482	6.40	6.45	85	82	109	116	30	30	50	50	120	82	13	39
33082	6.35	6.29	63	65	95	96	24	24	50	50	110	58	13	35
40182	6.05	6.05	44	47	71	71	22	21	70	60	90	47	13	32
40582	5.90	5.94	33	32	59	63	20	20	50	50	80	44	13	27
41982	6.00	5.98	30	34	59	60	22	22	60	60	65	66	12	25
42682	6.35	6.34	55	57	81	86	22	20	50	50	78	53	11	28
50682	6.55	6.60	74	82	102	117	34	33	40	40	110	125	13	35
52082	6.85	6.75	111	115	135	139	28	28	50	50	117	68	13	35
60382	6.75	6.72	118	119	145	145	29	28	70	70	117	69	13	38

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Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UEQ/L)	FLUORIDE (UEQ/L)
12480	.	.	.	.	.	.	.
22780	110	5	78	.	.	.	.
32880	100	20	235	.	.	.	.
40480	80	22	119	.	.	.	.
41180	200	47	263	.	.	.	.
41880	130	11	205	.	.	.	.
42580	110	10	139	.	.	.	.
50280	100	8	154	.	.	.	.
50980	110	11	114	.	.	.	.
51680	120	13	101	.	.	.	.
52380	120	15	85	.	.	.	.
53080	120	14	124	.	.	.	.
60680	140	13	74	.	.	.	.
61280	140	12	92	.	.	.	.
62780	180	17	149	.	.	.	.
71180	180	14	79	.	.	.	.
81180	290	11	130	.	.	.	.
90480	200	9	78	.	.	.	.
91980	280	13	164	.	.	.	.
100280	230	6	145	.	.	.	.
101680	200	8	168	.	.	.	.
102480	190	7	128	.	.	.	.
103080	190	9	159	.	.	.	.
110680	230	8	121	.	.	.	.
111380	160	5	141	.	.	.	.
120480	160	10	135	.	.	.	.
121880	150	7	101	.	.	.	.
10981	.	.	.	.	.	.	.
11481	200	16	133	.	.	.	.
20381	200	7	63	.	.	.	.
21781	100	13	101	.	.	.	.
22681	100	8	92	.	.	.	.
31981	100	7	83	.	.	.	.
32581	100	4	99	.	.	.	.
40781	100	5	111	.	.	.	.
41681	100	7	83	.	.	.	.
42281	70	7	56	.	.	.	.
43081	90	12	70	.	.	.	.
50781	100	11	60	.	.	.	.
52181	110	12	92	.	.	.	.
60481	150	15	78	.	.	.	.
72281	290	7	213	.	.	.	.
80581	340	18	98	.	.	.	.
81881	260	42	199	.	.	.	.
82781	240	11	106	.	.	.	.
90181	180	11	70	.	.	.	.
91081	170	7	75	.	.	.	.
92881	200	14	130	.	.	.	.
100781	200	7	109	.	.	.	.
101901	200	10	134	72.0	4.0	55.0	3.0
102981	200	13	122	56.0	3.0	58.0	3.0
111081	100	7	120	49.0	3.0	56.0	3.0
111981	100	8	129	50.0	5.0	59.0	3.0

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Appendix A. Continued.

120181	100	4	80	37.0	4.0	49.0	4.0
121481	100	3	80	43.0	6.0	63.0	3.0
123081	100	4	60	47.4	8.8	60.2	5.0
11982	120	5	57	45.0	8.0	59.0	3.0
20482	130	7	72	50.0	11.2	62.1	4.4
22382	130	6	74	55.0	10.5	55.0	3.7
30982	160	7	78	48.5	13.7	58.7	3.0
31682	150	10	114	44.2	15.3	65.9	2.3
32482	160	8	77	73.4	12.9	57.6	2.7
33082	200	19	121	37.9	9.8	55.3	2.3
40182	230	30	186	31.8	11.4	52.9	2.0
40582	130	12	175	35.3	6.5	56.2	2.7
41982	70	10	86	63.5	5.6	50.6	2.3
42682	60	5	77	32.6	2.6	56.5	3.0
50682	70	9	59	124.0	3.0	55.0	3.0
52082	90	10	57	40.0	1.0	50.0	3.0
60382	170	20	104	40.0	3.0	45.0	3.0

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Appendix A. Continued.

SINCLAIR BROOK

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
102981	5.25	5.46	7	14	34	52	26	26	70	70	55	78	15	41
111081	5.65	5.72	22	20	44	51	26	26	60	60	50	78	13	41
111981	5.45	5.45	14	17	38	45	24	26	60	60	55	74	13	41
120181	5.75	5.84	20	23	46	55	28	26	40	40	60	75	11	39
121481	5.70	5.68	14	19	41	45	24	24	30	30	55	70	11	38
123081	5.90	5.87	20	23	51	50	24	24	30	30	55	70	10	39
11982	5.75	5.79	21	22	48	51	28	28	30	30	55	71	12	37
21182	5.85	5.76	16	22	51	51	26	24	20	20	55	69	11	36
22382	6.00	5.92	31	27	61	54	25	25	30	30	55	72	11	39
30982	5.80	5.82	23	24	48	55	26	26	30	30	60	77	12	45
31582	5.55	5.59	13	16	41	45	26	26	30	30	60	67	13	44
32382	5.80	5.84	19	24	46	54	24	24	30	30	60	72	12	44
33082	5.65	5.68	16	17	44	44	24	24	40	40	60	67	14	44
40182	5.10	5.02	-1	-3	31	26	24	24	50	60	55	43	18	38
40582	5.25	5.25	1	7	31	33	23	23	30	30	50	51	15	36
41982	5.35	5.34	2	5	31	32	21	20	40	40	41	50	13	30
42682	5.45	5.45	6	10	37	36	20	19	40	40	38	51	12	29
50682	5.85	5.81	15	17	44	45	22	21	40	40	44	61	12	35
52082	6.15	6.12	31	34	54	61	22	22	40	40	48	70	14	37
60382	5.45	5.45	16	17	45	49	25	24	100	100	62	69	12	42

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Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UEQ/L)	FLUORIDE (UEQ/L)
102981	100	22	152	63.0	19.0	69.0	1.0
111081	100	16	149	65.0	18.0	63.0	1.0
111981	100	18	190	60.0	23.0	73.0	2.0
120181	90	18	95	59.0	25.0	69.9	2.5
121481	80	18	98	52.0	26.0	72.0	1.0
123081	80	13	70	55.1	27.5	68.0	1.3
11982	90	9	82	52.7	27.3	69.2	1.3
21182	80	8	81	50.7	26.5	65.3	1.3
22382	80	6	86	51.8	28.8	65.9	1.3
30982	70	14	112	50.1	24.2	64.4	0.0
31582	60	18	104	49.2	25.8	71.4	1.3
32382	40	10	95	45.1	30.3	68.5	1.3
33082	60	16	101	44.6	32.6	64.1	1.3
40182	160	42	342	30.0	34.6	57.1	1.0
40582	30	22	111	43.1	25.0	63.6	1.3
41982	40	21	117	111.0	15.8	59.9	1.0
42682	60	13	111	32.6	13.2	58.7	1.0
50682	40	13	115	45.0	14.0	27.0	1.0
52082	60	13	100	50.0	7.0	60.0	2.0
60382	140	18	113	46.0	8.0	50.0	2.0

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Appendix A. Continued.

MACHIAS RIVER

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
12480	6.30	.	82	.	116	.	.	.	.	.	.	.	.	.
22780	6.40	6.50	108	106	142	138	29	.	60	.	116	90	13	37
32880	6.25	.	59	.	84	.	21	.	60	.	85	68	12	30
40480	6.35	.	59	.	88	.	21	.	70	.	86	64	11	30
41180	5.95	.	30	.	61	.	20	.	70	.	74	59	15	30
41880	6.00	.	35	.	62	.	24	.	70	.	84	67	12	30
42580	6.10	.	45	.	65	.	21	.	60	.	82	64	12	30
50280	6.05	.	31	.	57	.	19	.	80	.	81	61	12	29
50980	6.15	.	44	.	68	.	20	.	70	.	80	63	12	28
51680	6.35	.	53	.	83	.	22	.	60	.	82	64	12	30
52380	6.25	.	44	.	68	.	24	.	50	.	87	65	12	31
53080	6.50	.	64	.	90	.	24	.	50	.	91	67	13	31
60680	6.55	.	58	.	101	.	24	.	50	.	90	72	15	31
61280	6.85	.	71	.	104	.	22	.	70	.	88	71	14	31
62780	6.90	.	83	.	108	.	24	.	50	.	93	71	13	33
71180	6.85	.	93	.	122	.	37	.	50	.	93	77	13	34
81180	6.75	.	97	.	.	.	25	.	70	.	92	85	14	36
90480	6.80	.	124	.	.	.	26	.	40	.	102	85	16	39
91980	6.55	.	72	.	.	.	28	.	100	.	112	89	15	43
100280	6.35	.	69	.	.	.	26	.	90	.	103	82	13	39
101680	6.25	.	56	.	.	.	.	.	.	.	98	73	13	38
102480	6.40	.	64	.	.	.	29	.	70	.	92	70	13	35
103080	6.20	.	51	.	.	.	24	.	70	.	95	71	13	38
110680	6.40	.	59	.	.	.	25	.	70	.	90	70	12	35
111380	6.25	.	47	.	.	.	28	.	60	.	92	71	12	36
120480	5.60	.	19	.	.	.	23	.	90	.	80	64	10	33
121880	6.15	.	55	.	78	.	24	.	60	.	95	77	11	37
10981	6.05	.	73	.	.	.	23	.	80	.	.	.	.	.
11481	6.15	.	71	.	101	.	28	.	70	.	90	70	13	33
20381	6.25	.	77	.	104	.	27	.	70	.	95	74	13	33
21781	5.85	.	40	.	66	.	25	.	70	.	80	65	13	33
22681	6.15	.	42	.	77	.	26	.	80	.	80	65	10	33
31981	6.30	.	55	.	81	.	24	.	70	.	85	65	10	33
32581	6.20	.	63	.	89	.	29	.	60	.	80	65	10	33
40781	5.95	.	45	.	74	.	24	.	70	.	75	61	13	33
41681	6.00	.	31	.	62	.	25	.	40	.	70	57	10	25
42281	6.15	.	39	.	51	.	23	.	40	.	90	70	10	33
43081	6.00	.	43	.	61	.	24	.	80	.	85	74	10	33
50781	6.15	.	51	.	79	.	24	.	60	.	90	74	13	25
52181	6.25	.	52	.	79	.	26	.	80	.	70	87	10	33
60481	6.35	.	62	.	92	.	29	.	90	.	95	78	10	33
72281	5.65	.	40	.	64	.	24	.	200	.	115	83	10	33
80581	6.50	6.50	76	79	116	116	26	27	70	80	105	87	13	41
81881	5.40	5.40	15	19	59	59	26	26	100	120	120	70	13	33
82781	6.35	6.35	60	62	89	89	32	25	.	.	100	74	13	33
90181	6.45	.	65	.	92	.	23	22	.	.	95	74	13	33
91081	6.50	6.45	76	67	116	104	24	24	60	70	90	74	13	33
92881	5.75	.	32	.	59	.	22	.	110	.	75	70	10	33
100781	6.15	6.05	42	47	73	76	22	22	100	90	75	70	10	33
101981	.	.	.	.	.	.	.	.	.	.	75	74	10	33
102981	5.70	5.88	27	38	58	78	23	23	120	120	75	70	10	33
111081	6.05	6.13	37	48	71	81	24	24	100	100	75	70	10	33
111981	5.95	5.99	43	44	68	76	24	22	90	90	70	70	10	33

Appendix A. Continued.

120181	6.25	6.28	61	59	81	91	23	24	90	90	90	65	10	33
121481	6.10	6.12	42	46	68	75	22	23	80	80	85	65	10	33
123081	6.25	6.22	45	51	77	83	24	24	80	80	85	70	8	33
11982	5.90	6.01	46	42	71	74	26	26	80	80	85	71	9	29
20482	5.85	5.88	48	52	78	86	24	24	70	70	85	67	9	29
21182	5.90	5.89	51	50	87	85	26	26	70	70	85	72	9	29
22382	6.10	6.08	60	61	95	97	26	26	80	80	90	70	9	30
30982	6.05	6.10	58	60	89	94	26	26	80	90	100	74	11	34
31682	5.95	6.02	50	54	75	84	26	26	80	70	95	72	12	32
32482	6.15	6.26	54	60	79	91	24	24	70	70	95	70	10	32
33082	6.20	6.15	48	51	78	80	22	22	80	80	90	68	11	31
40182	5.85	5.85	36	35	61	60	24	20	80	80	80	57	11	28
40582	5.70	5.71	19	21	48	50	22	21	60	60	75	57	11	26
41982	5.75	5.74	21	25	51	53	18	18	80	80	57	52	9	22
42682	5.95	5.93	25	31	58	60	18	18	70	70	58	54	9	22
50682	6.30	6.11	32	41	70	68	19	19	60	60	63	54	8	23
52082	6.45	6.45	51	52	77	78	20	20	60	60	68	60	9	25
60382	6.40	6.34	68	67	93	92	22	22	90	90	77	67	10	28

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Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEG/L)	NITRATE (UEG/L)	SULFATE (UEG/L)	FLUORIDE (UEG/L)
12480	.	.	.	.	.	.	.
22780	120	6	162	.	.	.	.
32880	120	17	272	.	.	.	.
40480	120	15	148	.	.	.	.
41180	250	31	344	.	.	.	.
41880	140	16	255	.	.	.	.
42580	140	13	146	.	.	.	.
50280	130	13	245	.	.	.	.
50980	120	12	159	.	.	.	.
51680	90	14	146	.	.	.	.
52380	120	16	127	.	.	.	.
53080	100	16	169	.	.	.	.
60680	120	18	121	.	.	.	.
61280	110	15	124	.	.	.	.
62780	130	20	103	.	.	.	.
71180	110	14	76	.	.	.	.
81180	160	14	85	.	.	.	.
90480	120	14	47	.	.	.	.
91980	280	59	200	.	.	.	.
100280	170	16	141	.	.	.	.
101680	140	17	164	.	.	.	.
102480	120	12	130	.	.	.	.
103080	150	17	159	.	.	.	.
110680	120	11	117	.	.	.	.
111380	150	12	187	.	.	.	.
120480	140	22	150	.	.	.	.
121880	130	16	148	.	.	.	.
10981	.	.	.	.	.	.	.
11481	200	.	11	.	.	.	.
20381	200	9	109	.	.	.	.
21781	200	16	155	.	.	.	.
22681	200	13	128	.	.	.	.
31981	200	13	147	.	.	.	.
32581	200	13	101	.	.	.	.
40781	100	18	129	.	.	.	.
41681	100	10	113	.	.	.	.
42281	90	12	86	.	.	.	.
43081	100	10	102	.	.	.	.
50781	100	10	96	.	.	.	.
52181	100	7	175	.	.	.	.
60481	150	14	103	.	.	.	.
72281	350	41	268	.	.	.	.
80581	210	14	103	.	.	.	.
81481	330	46	272	.	.	.	.
82781	200	15	88	.	.	.	.
90181	170	12	66	.	.	.	.
91081	160	10	66	.	.	.	.
92881	200	17	154	.	.	.	.
100781	100	11	111	.	.	.	.
101981	100	14	105	.	.	.	.
102981	200	13	148	47.0	0.0	54.0	.
111081	100	9	122	49.0	1.0	52.0	4.0
111981	200	13	148	44.0	2.0	52.0	4.0

Appendix A. Continued.

120181	200	7	124	38.0	6.0	53.0	4.0
121481	200	10	139	38.0	2.0	53.0	4.0
123081	200	7	114	39.0	3.0	51.0	4.0
11982	140	8	120	43.4	2.3	53.8	3.8
20482	160	10	131	49.2	3.9	54.1	4.2
21182	160	10	125	43.9	3.8	53.5	4.0
22382	150	8	102	51.2	4.0	52.5	4.0
30982	230	9	124	24.2	2.4	31.9	3.3
31682	200	12	117	49.2	5.6	58.1	3.3
32482	210	10	115	46.9	5.6	54.4	3.3
33082	220	11	116	41.8	4.5	52.9	3.7
40182	260	23	147	59.0	5.5	55.0	1.0
40582	190	9	106	44.3	3.2	51.2	3.0
41982	130	14	118	34.5	3.2	46.9	2.7
42682	120	13	98	31.5	2.6	47.8	3.0
50682	140	9	110	33.0	11.0	48.0	3.0
52082	110	9	81	37.0	0.8	43.0	3.0
60382	190	14	110	42.0	0.8	39.0	4.0

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Appendix A. Continued.

KEPWIN BROOK

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
22780	6.15	.	99	.	128	.	26	.	30	.	115	93	15	39
32880	5.45	.	11	.	42	.	20	.	60	.	54	66	12	23
40480	5.65	.	20	.	50	.	18	.	60	.	51	65	14	21
41180	5.05	.	-3	.	29	.	21	.	80	.	59	50	16	25
41880	5.25	.	5	.	33	.	20	.	70	.	59	67	15	26
42580	5.35	.	8	.	36	.	20	.	80	.	61	65	15	26
50280	5.00	.	2	.	33	.	20	.	100	.	60	66	15	25
50980	5.10	.	5	.	33	.	20	.	100	.	59	64	13	26
51680	5.50	.	19	.	46	.	20	.	80	.	57	69	13	25
52380	5.80	.	33	.	60	.	28	.	70	.	61	74	13	26
53080	5.80	.	36	.	61	.	24	.	60	.	63	79	16	26
60680	5.85	.	27	.	70	.	26	.	90	.	69	86	20	27
61780	6.05	.	35	.	67	.	22	.	90	.	67	82	15	26
62780	6.20	.	66	.	94	.	24	.	70	.	74	88	18	29
71180	6.20	.	83	.	111	.	29	.	80	.	81	90	15	31
81180	6.15	.	94	.	.	.	26	.	90	.	90	96	16	35
90480	6.30	.	123	.	.	.	26	.	60	.	91	97	18	35
91980	5.35	.	15	.	.	.	32	.	140	.	134	102	12	53
100280	5.75	.	52	.	.	.	28	.	100	.	102	97	18	41
101690	5.35	.	26	.	.	.	.	.	.	.	95	92	17	41
102480	5.75	.	33	.	.	.	32	.	120	.	84	86	12	36
103080	5.25	.	14	.	.	.	26	.	100	.	88	78	11	39
110680	5.55	.	28	.	.	.	26	.	100	.	76	80	11	33
111380	5.20	.	5	.	.	.	31	.	80	.	86	82	11	38
120480	4.85	.	-7	.	.	.	25	.	110	.	71	67	8	33
121880	5.60	.	30	.	.	.	21	.	70	.	61	81	10	27
20381	6.00	.	53	.	78	.	23	.	60	.	65	74	13	25
21781	5.15	.	8	.	32	.	24	.	70	.	60	65	13	25
22681	5.35	.	15	.	44	.	20	.	70	.	50	65	10	25
32581	5.95	.	41	.	74	.	23	.	60	.	55	70	10	16
40781	5.15	.	13	.	35	.	26	.	70	.	55	52	10	25
41681	5.20	.	-2	.	27	.	24	.	80	.	50	61	10	25
42281	5.55	.	7	.	25	.	20	.	70	.	60	78	10	25
43081	5.25	.	11	.	33	.	24	.	90	.	70	78	8	25
50781	5.65	.	34	.	56	.	21	.	90	.	65	83	10	25
52181	5.15	.	7	.	40	.	27	.	100	.	130	91	10	49
60481	5.30	.	19	.	50	.	28	.	100	.	70	91	10	33
72281	4.95	.	9	.	35	.	28	.	280	.	125	96	8	49
80581	5.60	5.60	55	58	95	99	25	25	140	150	90	100	10	33
81881	4.70	4.65	-24	-22	20	22	33	36	270	>00	120	83	8	49
82781	5.50	5.50	34	35	63	64	24	24	.	.	75	96	10	33
90181	5.65	.	49	.	79	.	22	20	.	.	70	100	10	25
91081	5.65	5.65	42	35	84	79	22	20	140	140	80	100	10	25
92881	4.90	.	-8	.	25	.	24	.	160	.	65	74	10	33
100781	5.05	5.10	11	6	40	36	23	21	120	110	60	78	13	25
101981	5.15	5.33	12	35	46	79	28	.	140	.	70	87	15	33
102981	4.90	5.04	-4	-1	25	48	26	30	150	150	70	78	13	33
111081	5.05	5.18	1	6	31	43	24	24	130	130	60	78	10	33
111981	5.00	5.06	3	7	31	39	23	23	120	120	60	78	10	25
120181	5.45	5.52	16	19	41	54	22	22	80	80	55	76	8	23
121481	5.30	5.28	12	7	38	38	22	22	70	70	50	67	8	21
123081	5.65	5.68	18	25	51	57	22	22	70	70	50	77	8	20
11982	5.55	5.58	22	21	46	52	23	23	70	70	50	74	9	20

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Appendix A. Continued.

21182	5.60	5.56	23	22	57	55	20	20	60	60	50	74	10	21
30882	5.75	5.79	39	38	63	70	23	23	70	70	65	74	11	27
31582	5.45	5.56	17	24	44	57	23	24	80	70	65	73	11	28
32382	5.70	5.74	31	37	58	68	23	23	70	70	60	74	11	26
40182	5.25	5.19	9	11	41	40	22	22	100	100	65	56	13	29
40582	4.90	4.98	-5	-3	20	26	22	27	90	90	55	51	10	24
41982	5.10	5.09	-1	1	28	31	18	18	90	90	39	52	9	19
42682	5.20	5.10	1	-1	37	29	18	18	80	80	38	57	8	18
50682	5.30	5.28	2	5	34	37	18	19	80	80	39	54	9	18
52082	5.85	5.87	31	34	54	61	20	20	70	70	49	72	12	21
60382	5.20	5.25	13	19	42	50	23	23	140	140	76	70	8	31

BEST COPY AVAILABLE

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Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEG/L)	NITRATE (UEG/L)	SULFATE (UEG/L)	FLUORIDE (UEG/L)
22780	650	31	614	.	.	.	.
32880	80	18	335	.	.	.	.
40480	90	17	344	.	.	.	.
41180	110	36	231	.	.	.	.
41880	130	23	387	.	.	.	.
42580	160	18	196	.	.	.	.
50280	160	17	288	.	.	.	.
50980	180	12	190	.	.	.	.
51680	120	7	155	.	.	.	.
52380	120	7	148	.	.	.	.
53080	100	11	139	.	.	.	.
60690	130	5	184	.	.	.	.
61280	120	5	190	.	.	.	.
62780	140	7	143	.	.	.	.
71180	150	4	134	.	.	.	.
81180	200	9	153	.	.	.	.
90480	190	4	121	.	.	.	.
91980	280	19	313	.	.	.	.
100280	230	7	232	.	.	.	.
101680	240	11	241	.	.	.	.
102480	190	8	220	.	.	.	.
103080	220	11	243	.	.	.	.
110680	200	9	209	.	.	.	.
111380	230	9	243	.	.	.	.
120480	200	10	188	.	.	.	.
121880	130	7	156	.	.	.	.
20381	100	3	96	.	.	.	.
21781	100	14	159	.	.	.	.
22681	100	9	126	.	.	.	.
32581	100	3	91	.	.	.	.
40781	100	17	146	.	.	.	.
41681	100	9	136	.	.	.	.
42281	50	6	116	.	.	.	.
43081	120	8	172	.	.	.	.
50781	80	5	120	.	.	.	.
52181	160	11	145	.	.	.	.
60481	130	8	215	.	.	.	.
72281	340	20	417	.	.	.	.
80581	320	14	225	.	.	.	.
81881	320	26	337	.	.	.	.
82781	200	9	233	.	.	.	.
90181	160	8	173	.	.	.	.
91081	200	7	165	.	.	.	.
92881	200	16	247	.	.	.	.
100781	200	11	206	.	.	.	.
101981	200	16	210	62.0	0.0	59.0	8.0
102981	200	14	212	52.0	1.0	57.0	7.0
111081	200	9	193	47.0	0.0	56.0	8.0
111981	200	11	209	43.0	0.0	60.0	8.0
120181	110	5	140	54.0	0.0	56.0	8.0
121481	110	5	126	44.0	0.0	57.0	7.0
123081	130	4	137	45.0	1.0	56.0	8.0
11982	90	4	111	51.3	2.5	53.4	7.6

Appendix A. Continued.

21182	100	5	107	48.2	3.0	52.9	7.1
30882	90	5	104	45.4	2.4	53.1	7.7
31582	110	7	128	33.8	0.8	59.4	5.7
32382	110	3	116	42.0	7.9	73.9	2.0
40182	140	13	145	28.6	0.8	54.9	5.3
40582	100	11	145	38.8	0.4	54.9	4.7
41982	80	8	99	31.4	0.4	45.7	4.0
42682	60	5	105	30.0	0.8	51.0	5.0
50682	70	5	105	33.0	11.0	51.0	5.0
52082	90	5	92	.	.	.	.
60382	180	13	220	42.0	2.0	43.0	6.0

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Appendix A. Continued.

HOLMES BROOK

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEG/L)	ALK (F.E.P) (UEG/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEG/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEG/L)
102981	5.15	5.34	8	15	41	61	28	28	150	150	85	78	8	58
111081	5.50	5.65	23	26	56	70	26	26	140	140	70	83	5	49
111981	5.25	5.35	12	22	46	55	25	25	140	140	80	83	8	58
120181	5.95	5.96	33	42	64	76	24	24	80	80	65	80	7	39
121481	5.80	5.80	26	27	51	59	22	22	70	70	55	74	6	38
123081	6.05	6.07	45	51	75	81	24	24	70	70	60	74	6	36
21182	5.90	5.83	42	38	73	75	22	21	50	50	60	75	6	35
33082	5.70	5.71	30	28	56	58	21	21	60	60	60	68	8	37
40182	5.25	5.20	8	8	38	31	20	20	60	60	50	47	10	34
40582	5.05	5.05	4	-2	27	28	22	22	50	50	50	57	9	35
42682	5.75	5.70	19	21	56	48	18	18	70	70	42	59	7	29
50682	6.02	6.15	39	35	68	66	24	23	100	90	50	68	9	33
52082	6.45	6.44	69	70	92	98	21	21	60	60	69	77	8	37
60382	5.35	5.43	29	35	62	69	24	24	190	190	96	71	7	57

Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UEQ/L)	FLUORIDE (UEQ/L)
102981	200	18	237	74.0	3.0	54.0	2.0
111081	300	11	190	73.0	0.0	52.0	1.0
111981	300	14	204	65.0	6.0	59.0	2.0
120181	180	7	146	68.0	2.0	56.0	2.0
121481	160	6	145	53.0	2.0	56.0	1.0
123081	150	4	111	53.8	5.0	52.4	2.5
21182	170	8	141	53.6	6.8	51.8	1.3
33082	180	9	141	47.7	5.7	56.5	1.0
40182	240	20	178	36.1	6.1	44.1	1.0
40582	140	20	140	65.5	1.6	50.0	1.0
42682	120	6	132	38.2	0.0	45.7	1.0
50682	190	4	176	48.0	0.8	39.0	1.0
52082	190	7	148	51.0	0.8	38.0	2.0
60382	390	18	415	39.0	4.0	33.0	2.0

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Appendix A. Continued.

OLD STREAM

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
21781	6.05	.	68	.	89	.	28	.	60	.	95	70	13	33
22681	6.35	.	69	.	102	.	29	.	60	.	95	70	13	33
31981	6.60	.	114	.	139	.	31	.	50	.	125	70	10	41
32581	6.55	.	114	.	139	.	33	.	40	.	125	74	10	41
40781	5.90	.	32	.	66	.	22	.	70	.	65	57	13	25
41681	6.15	.	74	.	102	.	30	.	60	.	95	70	13	33
42281	6.25	.	93	.	119	.	29	.	50	.	125	87	10	41
43081	6.25	.	74	.	96	.	30	.	80	.	110	87	10	41
50781	6.65	.	86	.	119	.	29	.	80	.	120	87	10	41
52181	6.65	.	96	.	125	.	31	.	80	.	90	78	10	33
60481	6.65	.	115	.	145	.	35	.	100	.	130	91	10	49
72281	5.45	.	36	.	64	.	27	.	200	.	130	87	10	49
80581	6.65	6.55	130	130	163	163	32	32	120	120	140	91	10	49
81881	5.95	5.95	56	54	94	94	30	28	140	120	140	83	10	49
82781	6.65	6.65	100	102	134	139	32	32	.	.	145	91	10	49
90181	6.65	.	120	.	152	.	30	30	.	.	145	100	13	49
91081	6.70	6.75	120	121	171	163	30	30	100	110	140	96	10	49
92881	5.95	.	56	.	84	.	25	.	160	.	110	74	13	41
100781	6.40	6.30	78	83	109	114	28	27	110	110	110	78	10	41
101981	6.15	6.26	57	65	83	100	25	.	100	.	115	87	13	41
102981	6.00	6.20	49	66	85	104	28	28	110	110	110	78	13	49
111081	6.40	6.60	86	89	117	132	29	29	100	100	120	78	10	49
111981	6.20	6.17	57	55	88	90	24	24	110	110	100	78	10	41
120181	6.50	6.50	101	96	124	126	30	30	80	80	120	74	9	43
121481	6.45	6.48	88	97	115	123	28	28	70	70	115	74	9	43
123081	6.65	6.61	119	122	149	153	32	32	60	60	135	74	9	44
11982	6.25	6.28	101	101	132	135	34	34	60	60	130	77	9	44
20482	6.10	6.15	88	89	119	123	30	30	70	70	110	72	8	39
21182	6.15	6.15	99	98	128	128	31	32	60	60	120	74	9	41
22382	6.50	6.53	130	134	159	165	34	34	60	60	140	82	9	49
30982	6.35	6.40	105	111	136	142	34	33	70	70	135	84	11	46
31682	6.25	6.25	82	81	107	111	32	32	70	70	115	82	11	43
32482	6.50	6.55	88	88	112	117	30	30	70	70	115	83	11	44
33082	6.35	6.36	86	85	107	110	28	28	70	70	115	78	12	44
40182	5.75	5.70	32	31	57	58	22	22	70	70	75	64	11	33
40582	5.75	5.76	32	32	57	57	23	23	60	60	75	57	11	32
41982	5.80	5.84	24	27	51	57	19	19	60	60	105	52	9	24
42682	6.25	6.18	43	47	71	74	22	21	60	60	65	59	9	27
50682	6.55	6.65	86	88	112	122	26	25	60	60	98	67	9	35
52082	6.80	6.78	126	127	150	153	30	30	50	50	129	78	10	44
60382	6.65	6.65	119	124	145	152	28	28	90	90	118	84	9	44

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Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UEQ/L)	FLUORIDE (UEQ/L)
21781	100	24	119	.	.	.	.
22681	200	19	123	.	.	.	.
31981	100	12	93	.	.	.	.
32581	100	10	86	.	.	.	.
40781	100	15	129	.	.	.	.
41681	100	11	140	.	.	.	.
42281	90	9	77	.	.	.	.
43081	110	11	99	.	.	.	.
50781	110	16	86	.	.	.	.
52181	110	11	100	.	.	.	.
60481	160	13	97	.	.	.	.
72281	310	62	93	.	.	.	.
80581	250	21	127	.	.	.	.
81881	320	36	271	.	.	.	.
82781	230	16	149	.	.	.	.
90181	220	15	.	.	.	.	.
91081	250	12	105	.	.	.	.
92881	200	22	167	.	.	.	.
100781	200	20	141	.	.	.	.
101981	200	15	137	49.0	1.0	52.0	5.0
102981	200	17	177	62.0	1.0	57.0	2.0
111081	200	10	106	61.0	1.0	57.0	2.0
111981	200	14	157	57.0	2.0	59.0	2.0
120181	120	10	121	56.0	1.0	59.0	2.0
121481	120	9	101	51.0	2.0	59.0	2.0
123081	110	9	85	55.0	4.0	61.0	2.0
11982	120	9	75	61.5	5.0	60.2	1.9
20482	120	16	94	61.5	6.3	62.1	2.4
21182	120	12	97	54.3	4.5	58.2	1.7
22382	100	8	85	89.2	6.1	60.6	1.3
30982	190	16	132	69.6	6.8	61.2	1.7
31682	190	12	124	74.6	7.3	65.0	1.7
32482	200	9	103	69.6	6.5	60.6	2.0
33082	190	12	89	53.2	4.5	55.9	1.3
40182	190	26	147	58.8	3.2	50.6	1.3
40582	200	17	104	54.5	2.4	54.3	1.3
41982	90	19	106	43.1	1.6	45.7	1.3
42682	70	9	102	46.0	0.8	51.0	1.0
50682	90	12	85	51.0	0.8	51.0	1.0
52082	110	19	67	59.0	0.8	49.0	2.0
60382	180	30	138	59.0	0.8	45.0	2.0

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Appendix A. Continued.

BOWLES BROOK

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
102981	4.90	5.05	-2	3	27	49	30	30	140	140	75	78	13	41
111081	5.15	5.29	7	16	34	49	28	28	130	130	70	78	10	41
111981	4.95	4.98	-3	2	31	35	27	26	140	140	65	74	10	35
120181	5.95	5.89	41	43	71	76	26	26	80	80	80	80	9	44
121481	5.75	5.78	29	28	61	64	24	24	80	80	70	74	9	39
121681	5.60	5.71	17	22	48	58	24	24	70	70	-	-	-	-
123081	6.05	6.05	41	50	78	82	26	26	70	70	75	77	9	41
11982	5.95	6.01	47	48	77	81	28	28	70	70	75	81	9	44
21182	5.80	5.73	38	43	69	73	26	25	70	70	70	80	9	39
30882	5.90	5.87	49	48	78	77	27	27	70	70	80	87	11	48
31582	5.35	5.44	18	20	44	53	25	27	70	70	75	80	12	42
32382	5.85	5.86	32	35	61	69	26	25	70	70	75	83	11	42
40182	5.00	4.96	9	-1	33	27	23	23	80	80	60	55	14	32
40582	5.00	4.98	4	3	25	28	24	24	60	60	55	56	12	30
41982	5.05	5.06	0	0	27	28	20	20	80	80	38	48	10	23
42682	5.35	5.32	8	12	37	37	18	18	80	80	43	53	10	26
50682	5.92	6.00	34	37	66	71	22	22	90	90	57	67	8	34
52082	6.55	6.55	87	90	112	123	26	26	110	110	81	88	12	50
60382	5.40	5.48	32	34	57	66	26	26	150	150	85	80	10	48

Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEG/L)	NITRATE (UEG/L)	SULFATE (UEG/L)	FLUORIDE (UFG/L)
102981	200	21	312	77.0	0.0	65.0	.
111081	200	13	277	54.8	0.7	65.5	2.0
111981	200	22	287	59.0	9.0	65.0	2.0
120181	140	10	181	54.0	6.0	65.0	2.0
121681	110	11	189	53.2	1.2	64.1	1.9
121681	.	.	.	.	.	.	.
123081	110	10	128	54.0	8.0	63.0	2.0
11982	100	10	144	57.7	7.5	63.1	2.5
21182	120	10	133	54.3	6.1	60.6	2.0
30882	150	15	104	62.7	10.5	66.9	2.0
31582	160	16	176	58.1	6.5	73.9	1.7
32382	160	9	174	56.1	6.1	64.1	1.7
40182	140	23	208	40.4	3.0	50.0	1.3
40582	1100	15	134	51.8	0.8	57.4	1.7
41982	100	12	130	35.3	8.1	48.1	1.3
42682	100	10	127	33.7	0.0	52.2	1.0
50682	100	9	129	47.0	1.0	53.0	2.0
52082	130	9	121	54.0	0.8	48.0	3.0
60382	240	29	365	54.0	2.0	46.0	2.0

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Appendix A. Continued.

HARMON BROOK

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
100781	6.10	6.05	65	59	96	94	24	24	70	70	-	-	-	-
102981	5.65	5.84	28	36	58	80	26	26	90	90	85	83	10	41
111081	5.55	6.09	49	50	75	90	26	26	70	70	75	83	8	41
111981	5.75	5.83	31	37	61	69	24	24	80	80	80	78	8	41
120181	6.05	6.12	56	55	78	87	26	26	40	40	85	81	7	41
121481	6.05	6.08	42	48	71	79	26	26	40	40	75	77	7	38
123081	6.25	6.26	66	69	92	97	26	26	40	40	85	79	7	39
11982	6.15	6.19	61	65	87	93	29	29	30	30	85	79	8	39
30882	6.10	6.17	69	72	98	104	28	28	50	50	95	78	9	46
31582	6.00	6.02	52	53	78	81	26	26	40	40	85	74	9	42
32382	6.25	6.30	68	69	92	98	26	26	30	30	85	77	9	43
33082	6.10	6.12	52	45	78	78	24	24	40	40	60	68	8	37
40182	5.55	5.54	22	22	51	50	20	22	60	60	70	48	12	35
40582	5.60	5.64	14	17	44	45	20	20	40	40	60	54	9	31
41982	5.70	5.78	19	22	46	50	18	18	50	50	49	54	7	26
42682	6.00	6.00	34	33	59	59	20	22	40	40	57	59	7	29
50682	6.25	6.26	55	57	81	86	26	26	50	50	72	73	9	35
52082	6.85	6.75	111	115	135	139	28	28	50	50	89	80	10	41
60382	5.85	5.92	53	58	83	96	26	26	120	120	93	74	6	44

Appendix A. Continued.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUMINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UEQ/L)	FLUORIDE (UEQ/L)
100781	.	.	.	.	.	.	.
102981	200	7	197	63.0	3.0	70.0	2.0
111081	200	4	141	65.0	1.0	70.0	2.0
111981	100	5	176	50.0	0.0	72.0	2.0
120181	80	4	130	42.0	4.0	62.0	2.0
121481	90	4	102	49.0	3.0	73.0	2.0
123081	70	3	89	50.0	7.5	69.9	2.5
11982	70	3	87	51.0	7.0	71.0	2.0
30882	190	8	89	48.6	8.3	70.6	1.7
31582	140	8	139	44.2	5.6	73.3	1.3
32382	140	6	91	45.4	5.6	68.3	1.3
33082	180	9	141	38.7	4.5	69.2	1.7
40182	210	22	180	33.3	2.4	58.0	1.3
40582	110	7	95	46.3	1.6	61.7	1.3
41982	50	3	54	34.1	0.8	59.3	1.7
42682	40	2	92	31.5	0.0	63.0	1.0
50682	90	7	86	44.0	0.8	63.0	1.0
52082	110	5	86	44.0	1.0	59.0	2.0
60382	180	13	268	34.0	0.8	45.0	2.0

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Appendix A. Continued.

WHITE RIVER, VERMONT

DATE	PH	PH	ALK (I.P) (UEQ/L)	ALK (I.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	ALK (F.E.P) (UEQ/L)	COND US/CM	COND US/CM	COLOR UNITS	COLOR UNITS	CALCIUM (UEQ/L)	SODIUM (UEQ/L)	POTASSIUM (UEQ/L)	MAGNESIUM (UEQ/L)
110581	7.16	.	230	.	260	.	.	.	.	.	305	100	10	58
111981	7.25	.	256	.	295	.	57	57	0	0	310	90	9	89
120181	7.20	.	263	.	295	.	60	60	0	0	320	102	10	90
120881	7.30	.	238	.	262	.	60	60	0	0	320	101	10	93
122381	7.05	.	270	.	291	.	65	64	0	0	345	108	10	99
123181	7.35	.	309	.	336	.	71	70	0	0	370	117	10	101
10882	7.15	.	224	.	244	.	57	56	0	0	310	94	9	90
11482	7.00	.	280	.	291	.	64	64	0	0	350	109	10	100
12182	7.10	.	334	.	366	.	67	68	0	0	375	115	10	103
12982	7.05	.	310	.	336	.	72	72	0	0	390	121	10	108
20582	7.05	.	168	.	204	.	53	53	0	0	260	116	10	76
21682	7.05	.	246	.	268	.	62	62	0	0	330	110	9	96
22682	6.70	.	247	.	262	.	80	80	0	0	438	143	12	127
31782	7.10	.	273	.	285	.	66	66	0	0	321	145	10	107
32282	6.60	.	202	.	221	.	66	66	10	0	331	151	10	109
40182	6.80	.	111	.	122	.	42	41	10	0	215	71	8	79
40982	6.90	.	188	.	197	.	62	62	0	0	313	124	9	97
41582	7.10	.	.	.	.	.	54	54	0	0	280	109	8	89
42382	6.70	.	138	.	148	.	44	44	0	0	239	79	9	77
50682	6.35	.	183	.	198	.	51	52	0	0	272	93	9	82
51482	6.45	.	231	.	244	.	62	62	0	0	329	116	11	95
52182	6.60	.	194	.	209	.	66	66	0	0	354	123	13	102
52782	6.45	.	239	.	262	.	68	68	0	0	370	129	13	105

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Appendix A. Concluded.

DATE	IRON (UG/L)	MANGANESE (UG/L)	ALUPINUM (UG/L)	CHLORIDE (UEQ/L)	NITRATE (UEQ/L)	SULFATE (UFC/L)	FLUORIDE (UEQ/L)
110581	0	10	9	103.0	40.0	143.0	2.0
111981	40	3	14	94.0	30.6	134.7	1.3
120181	30	5	14	106.0	35.3	136.7	1.3
120881	60	9	32	108.0	35.3	138.8	1.3
122381	20	3	5	118.1	38.9	140.7	2.0
123181	20	3	8	128.9	41.7	140.7	1.1
10882	30	2	17	97.6	38.9	134.7	1.1
11482	20	2	9	109.6	41.7	142.7	1.1
12182	10	3	4	119.3	44.4	140.7	1.1
12982	0	0	6	126.5	44.4	140.7	1.1
20582	70	8	54	136.1	45.0	120.4	1.3
21682	50	3	22	116.1	41.7	134.7	1.1
22682	60	6	20	163.9	50.0	148.8	1.1
31782	90	15	47	173.5	44.2	132.7	1.0
32282	270	33	115	194.0	44.4	134.7	1.1
40182	390	59	223	79.0	45.0	118.0	1.0
40982	0	13	20	160.2	55.6	132.7	1.1
41582	20	15	52	131.0	39.0	126.0	1.0
42382	150	20	98	86.0	47.0	118.0	1.0
50682	0	14	46	107.0	42.0	122.0	2.0
51482	20	12	31	141.0	36.0	128.0	2.0
52182	20	5	23	151.0	31.0	130.0	2.0
52782	20	4	16	159.0	28.0	132.0	1.0

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Appendix B

Salmon Redd Excavation

During November 1981 two naturally spawned Atlantic salmon redds were located and mapped, one each in Old Stream and Bowles Brook. On April 26, 1982, each redd was excavated using a hooded shovel (Hatch 1957) and eggs and fry were collected in a drift net (Jordan and Beland 1981) and preserved for later examination. Excavation of the marked Atlantic salmon redds was timed to occur after hatching of eggs but before emergence of fry. There were no live, unhatched eggs among those recovered.

Stream	Dead Eggs	Dead Fry	Live Fry	Total	Percent Mortality
Bowles	10	6	131	147	11
Old Stream	0	1	46	47	2

The Bowles Brook redd had higher mortality of both eggs and fry than did the Old Stream redd, although the total number of fish recovered was also larger. The dead fry were partially encapsulated in the egg membrane. Such failure to completely rupture the egg membrane has been reported previously for Atlantic salmon embryos exposed to acid stress (Peterson et al. 1980). The number of fry emerging in Old Stream in 1980-81 ranged from 91 to 109 for natural redds and 21 to 124 for artificial redds (Gustafson-Marjanen 1982), thus the number we recovered is reasonable.

The use of naturally spawned Atlantic salmon redds precludes the determination of total eggs deposited or total mortality. The drift net used was large enough to ensure the collection of all eggs. Fry that were already hatched could have migrated away from the egg pit through the gravel and may have been missed. Eggs that died during development may have disintegrated and would not be collected. The estimated total survival for Atlantic salmon eggs from eyed stage to emergence from natural redds in Old Stream during 1980-1981 was 5.8-6.4% (Gustafson-Marjanen 1982). In that study, excavation of natural redds following fry emergence resulted in recovery of only one or two dead eggs. No dead fry were found. We found no dead eggs and one dead fry in the Old Stream redd we excavated.

It is not possible to state conclusively that depressed pH and/or elevated aluminum concentrations resulted in decreased Atlantic salmon embryo and fry survival in Bowles Brook. Excavation of only one redd per stream does not permit calculation of confidence limits or tests of significance of mortality in the two streams. However the appearance of the dead fry from Bowles Brook does suggest that acid stress caused the mortality.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

A water chemistry survey was conducted in nine Atlantic salmon rivers in New England. Eight rivers are in Maine and contain native Atlantic salmon populations. One river is in Vermont and is undergoing restoration of the Atlantic salmon population. The rivers ranged in size from first order tributary streams to third order main stem rivers. All contained actual or potential Atlantic salmon spawning and nursery habitat. The chemistry of the Maine rivers was similar to that reported for other rivers located in areas where bedrock is low in acid neutralizing capacity and where precipitation is similarly acidic. The Vermont river had much higher concentrations of all ions except aluminum and hydrogen than the Maine rivers, especially calcium, magnesium, and bicarbonate, indicating the presence of carbonate mineral in the watershed of this river. The pH and aluminum concentrations in second and third order streams were well within safe limits for Atlantic salmon, even during periods of high discharge. First order streams, however, reached levels of pH and aluminum concentration that may be toxic to sensitive early life stages of Atlantic salmon, or during smoltification, although conditions were not as severe as those reported for Atlantic salmon streams in southern Norway or southwestern Nova Scotia, where Atlantic salmon populations have declined or disappeared apparently as a result of acidification.

17. Document Analysis a. Descriptors

acidification, pH, alkalinity, aluminum concentration, fisheries, water chemistry

b. Identifiers/Open-Ended Terms

Atlantic salmon, impacts, stress, metal contamination, water quality, acid rain, acid deposition

c. COSATI Field/Group

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